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PROCEEDINGS

SECOND MEETING, FIRST HALF, 67TH SESSION

The Second Meeting of the 67th Session of the Royal Aeronautical Society was held in the lecture theatre of the Royal Society of Arts, 18, John Street, Adelphi, London, W.C.2, on Thursday, October 29th, 1931, when a paper on "Accidents in Civil Aviation," by Captain A. G. Lamplugh, F.R.Ae.S., M.I.Ae.E., was read and discussed. The President (Mr. C. R. Fairey) in the Chair.

The PRESIDENT: The lectures delivered to the Royal Aeronautical Society never lacked variety, but never before had the Society listened to a lecture by anyone who was prepared to face, or who had the necessary knowledge to be able to inform the members upon, the question of aircraft accidents. Accidents were melancholy concomitants of aviation, but the scientific study of their causes and the statistical investigations to discover whether or not their incidence was increasing, held in it the real clue to the future success of aviation, or, at least, of civil aviation. Captain Lamplugh was very well known to the audience, and it would be agreed by all that there was no one better qualified than he to deal with the subject. He was the Surveyor and Underwriter of the British Aviation Insurance Group.

ACCIDENTS IN CIVIL AVIATION

BY

CAPTAIN A. G. LAMPLUGH, F.R.Ae.S., M.I.Ae.E.

I am aware that this is a rather unusual type of paper to be read before the Society. It deals very largely with the most deplorable side of civil aviation as distinct from any form of service aviation, and the only justification for such a paper is that it may bring to the notice of the members of the Society some facts concerning this side of aviation in a form not usually available, from which form may be more readily deduced the best means of combating some of the unnecessary and wasteful loss of life and material which aviation at present involves.

At the outset I think I ought to say that any views expressed in this paper must be considered as entirely personal, and although the figures have been collected from official and semi-official and private sources the graphs and deductions therefrom are very largely the result of personal calculations.

Several difficulties arise in placing the facts before you in a form which is definitely illustrative without being in any way misleading. In the first place, I feel sure that you will all appreciate that I must regard as confidential the names of companies, or types of aircraft or pilots involved in any particular accident, in view of the fact that incorrect conclusions might be drawn, and unnecessary harm might be done in certain cases to individuals or companies or to the cause of civil aviation. Another difficulty is that it is almost impossible to co-ordinate with accuracy the statistics published by various countries in respect of accidents, so as to arrive at any really accurate percentage of the number of

accidents of any particular type, per hour of flight, or per miles flown in the various countries with which we are concerned to-night.

There is a possible reason for this, in that aircraft accidents are nearly always capable of being debited to more than one heading in the usual form of statistics. In one country, for instance, when an accident occurs through an aircraft flying into the side of a hill in a period of bad visibility, the occurrence is put down to " an error of judgment in navigation." In another country the accident may be allocated to " bad weather " and yet in a third country to " error of judgment on the part of the pilot." The best that I have been able to do is to take various statistics and co-ordinate them so far as my personal knowledge of the accidents concerned and of the methods of the various countries concerned allows, but you will understand that any comparisons drawn under this method of calculation must be a matter to some extent of personal opinion and cannot form a conclusive guide as to the degree of safety which civil aviation in any one country enjoys as compared with civil aviation in another country.

Comparisons of Loss

In every accident there are invisible losses not disclosed to the public. The loss of revenue to the owner through losing the use of an aircraft is usually a serious item, sometimes more serious than the loss of the aircraft itself. In addition to this, there is the indirect loss caused by the effect of the accident on spectators, on the families and friends of those concerned in the accident, and on the general public through the medium of sensational Press publicity. These and other indirect forms of loss must be added to the actual cost of repairing and replacing the aircraft or personnel, and it is obvious therefore that the question of investigating accidents and of taking every possible step to minimise the burden carried by aviation in this respect is of primary importance.

I would ask you to put out of your minds any thought that I am discussing this matter from the point of view of insurance. It does not matter whether an aircraft is insured or not. It does not matter whether the crew or passengers and cargo involved in an accident are insured or not. The loss to the country and to civil aviation is ultimately the same.

Comparative Statistics

I propose now to give you some comparative percentages and statistics as to the cause of accidents. In judging these it is essential to remember that the mileage flown in the various countries under consideration varies greatly.

In reviewing the accidents of the past few years in Great Britain, France, Germany and America the first thing which strikes any observer is the large percentage of accidents falling in one form or another under the heading of " Error of Judgment." The figures vary slightly in accordance with each country's method of tabulating its accidents, but the error of judgment factor is at one and the same time the most alarming feature, and the most potential factor in retarding the development of civil aviation in all countries.

During the period under review, January, 1928, to date, errors of judgment in one form or another have been responsible for at least half the accidents which have occurred. During the same period accidents as a result of structural or mechanical breakdown have declined continuously until they have reached an average figure of approximately 20 per cent.

I think this comparison should receive very careful consideration. At a conservative estimate direct damage amounting to £1,500,000 has been caused to European civil aircraft, engines and equipment since January, 1928. This means a bill of at least £750,000 for personal errors, as against only £300,000 for mechanical or structural failures and only £90,000 for damage caused entirely

by flying in bad weather, which is the worst physical feature we have to deal with.

One may add to the figures given above anything up to 50 per cent. of this sum for indirect loss coming under the headings previously mentioned which gives the appalling total of £1,125,000, or about £240,000 a year for loss attributable to errors of judgment on the part of operating personnel.

The error of judgment factor may be conveniently divided into a " professional " and " amateur " category.

It is, however, necessary to bear in mind in making any such sub-division, that pilots in the two categories are usually flying entirely different types of aircraft and that while the professional has the advantage of a better organisation and radio communication, he is called upon to fly more or less continuously in bad weather and in darkness.

In 1926 the error of judgment factor for both classes was approximately 35 per cent. In 1930 the percentage for professionals had dropped to 17.06 per cent., whereas that for the amateur had fallen only to 33.65 per cent. To some extent this is accounted for by the fact that during this period there has been a great increase in amateur flying and a consequent increase in the number of comparatively inexperienced private owners.

Another interesting feature is that during the same period personal errors on the ground have increased in both classes from approximately 1.5 per cent. in 1926 to 6.16 per cent. in 1930.

One would expect this to be attributable to the increased number of aircraft using any particular aerodrome, with a consequent increase in the risk of collisions on the ground. In fact, however, the majority of personal errors on the ground by amateur pilots have been due to the starting up of engines with the throttle partially open and without chocks. No less than 17 accidents of this description have occurred during the past 18 months and it shows a lack of care in detail which is rather disturbing.

As regards professional pilots, personal errors on the ground are to some extent attributable to the era when wheel brakes were either in an experimental stage or non-existent, and the percentage in this class may be expected to decrease now that wheel brakes of a satisfactory type are coming into universal use.

Accidents due to weather and darkness are identical in both classes, but here again the comparison is rather misleading because the professional pilot flies to a far greater extent in bad weather and darkness than the amateur.

Those of us who have been advocates of the second class navigator's licence as an essential part of the professional pilot's equipment will find encouragement in noting that faulty navigation in the professional class shows a figure of only 2.84 per cent., whereas the amateur figure is 11.37 per cent. Furthermore, the professional figure, low as it is, is largely due to inaccurate wireless bearings taken and given during periods of bad atmospherics.

Failure of material follows the failure of personnel in all statistics, the majority of airframe failures without some contributory cause occur in comparatively new types, and so far as this country is concerned such failures in large passenger-carrying aircraft have been practically non-existent.

Failures in the air have occurred in light type aircraft, both in this country and abroad, to an extent far greater than in larger types, and while the risk of airframe failure is very remotely present in all classes it only reaches noticeable proportions in full-scale tests of comparatively new types and then chiefly in fighter or aerobatic types.

Large type passenger-carrying aircraft abroad have not had quite the same good experience which we have had, and in light type aircraft both at home and abroad, structural defects so far as the amateur is concerned are possibly traceable

to mishandling of aircraft through lack of experience or to the lack of skilled inspection.

One of the most illuminating features is the percentage of mortality amongst pilots. The danger period so far as age is concerned among professional pilots appears to be somewhere in the early twenties and between the ages of 30 and 40 the professional pilot's expectation of life appears to be good as compared with any other class of pilot, particularly if he is employed in handling large multi-engined aircraft on regular air lines.

I must not specify any particular type, but there is a definite ratio of accidents in comparison with various types; their manœuvrability, and their performance. High performance does not in itself signify liability to accident, but the fighter and aerobatic types are generally involved in more serious accidents than types which lack similar aerodynamic qualities. This is possibly due to the fact that the very qualities possessed by such types lead to errors of judgment in manœuvres.

A feature of interest is the comparative immunity from serious injuries enjoyed by passengers in large metal aircraft. The modern metal fuselage or hull has proved that it stands up very well indeed under impact and stress. This is especially true of the welded tubular steel type of construction. There are many cases where very serious damage has occurred to the airframe and engine, but the passengers have escaped with nothing worse than a few bruises.

Turning again to amateur pilots it is distressing to find the number of fatal and serious accidents caused through over confidence, inadequate training, carelessness, or deliberate foolhardiness. The danger periods in an amateur pilot's career appear to occur in general at three stages:—

(*a*) Between 20 and 30 hours, possibly as the result of a lack of secondary dual;
(*b*) Between 80 and 120 hours, generally through over confidence; and
(*c*) Between 500 and 600 hours.

This last period is not so easy to account for, but in general it may be attributed to the fact that the pilot has by this time acquired a reasonable degree of perfection in the handling of aircraft, but has not yet learned that no amount of skill will avail against the elements under certain conditions.

I think most experienced instructors will agree that the risks of the first two periods may be largely minimised by skilled instruction and careful secondary dual.

The main statistics of accidents for America are given under four headings, for England and France under six headings, and for Germany—as usual very thorough in these matters—under nine headings.

Germany is the only country in which the error of judgment factor has increased, but I attribute this not so much to the standard of pilotage as to the fact that Germany has attempted more than she can reasonably be expected to undertake on the subsidies allowed, and the German methods in assessment are perhaps more rigid than in some other countries under consideration.

In England the error of judgment factor has declined, in France it has remained more or less stationary despite their increased flying activities, and in America it has declined despite a very great increase in flying activities. The American results are to a certain extent due to more careful training in handling, organisation and airmanship.

I should like at this period to pay a tribute to the French, German and Belgian night flying services for their consistency in the face of really adverse weather conditions.

In dealing with accidents on the ground, the Germans give a heading under "landing grounds." The German curve in this respect rises very much for 1927

and 1928, due largely to the extraordinary increase in air transport operations in Germany during that period, in which many small towns embarked hastily upon municipal aerodromes, and the selection of sites was dictated rather by the urgency of the matter than by the suitability of the ground.

Again, Germany is the only country to give a separate heading for fire. This maintains a fairly even level from 1926 to June, 1927, but has shown a sharp decrease since that time.

As I stated previously, the figures given in this paper are only from main headings of causes.

All these headings are capable of sub-division, but I am afraid time does not permit of their being considered this evening.

Each country has also a heading, "Miscellaneous or Unusual Accidents," and amongst these the following material causes should be especially noted:—

Unmarked obstacles on aerodromes and obliteration of aerodrome markings.

Grazing of cattle on aerodromes.

At the moment of landing the cabin lights being switched on, the reflection from the windscreen completely blinding the pilot.

Holt flares setting fire to wing tips.

Pilots fainting at high altitude, or in aerobatics.

Batteries catching fire in the air.

Pilots abandoning the aircraft by parachute without sufficient reason, or "parachute consciousness."

Unknowingly landing at night or in bad visibility—generally due to faulty or lagging instruments.

Cargo shifting in bumpy weather owing to insecure stowage.

Wings of a folding wing aircraft not being properly locked home and partially opening during flight.

Aileron or elevator control cables crossed.

Hitting high tension wires in bad visibility.

Airframe and propeller damage as a result of hitting birds.

Incorrect W.T. bearings through atmospherics and jamming.

Taking off from unsuitable fields after a forced landing.

This last item is a particularly fruitful source of accident and should really come under the heading of errors of judgment. Even an experienced pilot who knows his machine thoroughly often finds some difficulty in deciding whether he can safely take-off from a strange field, bearing in mind the surface of the ground and the air currents which will be met with when taking-off owing to the nature of the surrounding country.

Looking a little more closely into the question of structural collapse either in the air, on the ground or water, one finds that the majority of accidents under this heading are undercarriage failures in land aircraft and main and wing-tip floats in seagoing aircraft, and I think it is preferable, while designing up to the highest factors for rough usage, to bear in mind that when failure must occur the lowest stressed component should be cheap and easily replaced and the damage as a result of failure of that component should be localised.

Structural failure in the air outside full-scale trials of a new type can sometimes be traced to aerobatics, or as a result of aerobatics, and while the loop and the spin are not potential factors in structural collapse, the roll and the inverted loop appear to be more of a cause of structural collapse than other manœuvres.

Of course, I am not including under this heading such items as terminal velocity dives or other tests to ascertain and eradicate an aerodynamic problem.

I think that structural failure could be more conveniently divided into two headings, the first one being that caused by airframe failures: and the second, airframe failures as a result of stress set up through severe mechanical breakdown or propeller trouble.

Quite a number of accidents have been caused under the latter heading, and recently the propeller of the port engine of a large tri-motor aircraft in the States failed in taking off, the engine coming clean out of the mounting and the airframe structure partially collapsing in the air to the extent that the machine became completely out of control and it resulted in the death of all on board.

I mention this point only because it is a source of trouble which will take a lot of getting over, and we have recently all been forcibly reminded in this country of something approaching the same sequence of events.

Mechanical breakdown is given nearly always under the heading of "structural failure," but as mechanical breakdown to-day is more a matter of metallurgical chemistry than anything else, and as we might be drawn into a discussion on the relative merits of air-cooled and water-cooled power units, I think we had better skip lightly over this controversial point. The weather is our next difficulty, and while we shall always presumably have to fly in rather inferior weather, I think it behoves us to improve bad weather flying facilities and training. Accidents due directly to weather are apparently rare in this country, and weather has always been a problem which we can only get over by practical bad-weather flying. This reference, of course, is obviously with regard to the amateur rather than the professional pilot. Other causes of accidents are so comparatively few that I do not think they are worth your consideration to-night, as we have considered the causes of the vast majority of accidents.

Investigation of Accidents

The preliminary step in the investigation of aviation accidents is very similar in all the countries under review.

The pilot or commander of an aircraft, or responsible member of the crew, or if they are not available, the police, are charged with the notification to the proper authorities.

The procedure up to this point is common throughout the world, but from here onwards it differs in certain essential features.

In France, when slight accidents occur (not involving serious injury to personnel), the causes are inquired into by the local police, and not by the representatives of the Air Ministry. In the cases of serious accidents, however, in addition to the police inquiry, the Air Ministry may also impound any portion of the aircraft for examination by its technical staff. The French do not, as a rule, make public the findings as to the cause of a serious aircraft accident.

A feature worthy of note is that the certificate of airworthiness for French civil aircraft is dealt with by a semi-official body, the Bureau Veritas, and France is the only country in the world to employ this medium.

As the aircraft automatically loses its certificate of airworthiness following an accident, the Bureau Veritas has the right to investigate the accident on its own before renewing the certificate of airworthiness.

Neither in England nor in America is very much notice taken of slight accidents. In America, however, reports of serious accidents are examined by the Accident Board of the Aeronautic Branch. This is composed of two pilots, a flight surgeon, an aeronautical engineer, a lawyer who has studied aviation, and a statistician.

You will note that America utilises the service of two practical pilots. This is an interesting and instructive development, for I am personally convinced that the accuracy of an investigation and findings very largely depends upon an examination by practical pilots, or examiners who have had recent flying experience.

In America, also, reports by the Departmental Inspector of Accidents are regarded as being strictly confidential and are never made public; and further power is added to the Departmental Inspector by the ruling that repairs cannot

be made to an aircraft which has suffered more than 50 per cent. damage, except by the manufacturer, unless any repairer is prepared to submit blue prints and stress analyses to the Department for approval.

In a country where distances are so vast, this seems at first sight a very arbitrary rule which must inevitably increase the cost of repairs to the owner or operator.

A striking illustration of the authority held by the Department of Commerce was an action taken in the spring of last year, when a tri-motor aircraft crashed in a central part of the States, resulting in the death of two pilots and six passengers.

One of the passengers was a famous American football coach, and the crash received the fullest publicity.

While the actual causes of the accident were never discovered with any degree of reliability, the Department stopped the flying of every single machine of that type in the States until a careful investigation had been made.

The aircraft was of a well-known thick-wing type, with built-up spar and three-ply covering, and some difficulty was found, I understand, in adequate internal inspection of the wing.

All this type of aircraft were subsequently released for operations, but, naturally, considerable harm had been done in the effect on the public and in the loss of revenue to the operators.

In Germany, in cases of serious accidents, the pilot, if available, or otherwise spectators, report to the nearest police station, where the matter is examined.

A report of the accident is forwarded, together with photographs, to the head police office of the province, and then goes to the Reichsverkehrsministerium and the Deutsche Versuchsanstalt fur Luftfahrt (D.V.L.).

If the accident appears due to the failure of material or construction, or the cause appears uncertain, the machine is impounded and thoroughly examined by the D.V.L. in Berlin. Here, again, it is the job of the police to collect pilots', passengers', and eye-witnesses' reports at the scene of the crash. In one case, however, the practice differs: accidents to the National Air Line—the Lufthansa—are investigated by a special commission of inquiry, under the presidency of an entirely independent person, where the whole cause of the accident is examined and reported on.

This applies to all but slight accidents, whereas in this country the system only applies to cases where the Secretary of State considers the matter of sufficient importance to order a public inquiry.

Germany intends, in the near future, to set up an official examining body to report on all accidents.

In the case of serious accidents in this country the Inspector of Accidents is charged with complete technical investigation, and, if it is considered necessary, the Secretary of State will order a public inquiry.

The Accidents Branch at the Air Ministry comes directly under the Secretary of the Air Ministry, and is therefore responsible to no other department, civil or military.

This is so obviously a sound procedure that I will not elaborate on it.

I have, however, for many years had the privilege of studying the methods employed by our own Accidents Department, and I have nothing but praise for the efficiency and impartiality of the system which they have adopted and the methods employed by the Inspector of Accidents and his staff.

The investigation of any accident is a very serious and responsible work, calling for a really specialised knowledge which can only be acquired by long experience.

It is quite reasonably possible for them to piece together the story from the wreckage and evidence of eye witnesses, if the personnel are not available, and to arrive eventually at a definite conclusion; and it requires the most painstaking efforts on the part of the investigating personnel.

The position and area of the wreckage, and more particularly the position in which wings, fuselage, engine, propeller, etc., are found, would often give a clue, and indentation in the ground and on various components are all of great importance.

For instance, the depth to which a leading edge or navigation light has penetrated the ground on one side more than another, is of value, as also is the exact loading at the time of the accident.

The careful analysis of the causes of failure of wires or plates, of fatigue in metal, and of highly-stressed components failing either under compression or tension, is all part of the work of this Department.

It should be appreciated that often before any investigation can be commenced the personnel have been removed, and further damage is often created in these operations, which to a certain extent makes the investigation of the accident difficult. (In Germany, the bodies of fatally injured personnel are not removed from the wreckage until official photographs have been taken.)

Eye-witnesses' evidence, although possibly quite inconclusive by itself, can only be taken to give some outline of the picture of the movements of the aircraft immediately prior to the crash.

Taken in conjunction with the story told by the wreckage of the aircraft, and analysis as previously outlined, it will enable the skilled investigator to deduce, without any reasonable doubt, the cause of the accident.

Some Possible Remedies

I presume it is expected that some suggestion should be made with regard to remedy. It is perhaps of little use collecting and laying before you a somewhat depressing assortment of statistics, and, therefore, if I may be so presumptuous as to give my own views, I will do so with great deference, leaving you free to draw your own conclusions from the points I have put before you.

1. I think an improvement in the standard of training for all classes could be effected, with a general increase in the standards of airmanship and navigation, and particularly the standards required for the " A " licence.

   At the moment the " A " licence is hardly a guarantee of ability for anything more than a few weeks, and unless the beginner who passes an " A " licence is carefully watched in the early stages by a senior man, he is very liable to be a potential source of danger to himself and to other unsuspecting people in the air and on the ground.

2. I would also add that I think that care in the selecting and licensing of Instructors is of very great importance.

   If the future generation of amateur pilots is going to be a credit to the country they should receive tuition from people whom the country recognises as being pre-eminently suitable to teach them.

3. Air Traffic Control at Aerodromes and along traffic routes is another matter of some importance. If air traffic is going to grow as we hope it will grow, stricter control will be required with more regard for practical regulations for ensuring safety of traffic.

4. The development of oil fuel and compression ignition engines.

5. Control at low speeds and any other safety devices in the form of blind flying equipment, slots, parachutes, and the like.

6. Design with a view to improved visibility.

7. As a final suggestion for safety, I should like to express the hope that the methods employed by the various departments of the Air Ministry in technical and administrative services should be allowed to maintain their present standard. We have, all of us, from time to time cursed at regulations and modifications and inspections, and though possibly some of the procedure is not quite so quick as we should like, I think we can all of us pay a tribute to the helpfulness and impartiality of the Air Ministry Departments and the standard they have built up in the airworthiness of British civil aircraft. It is an important point in the continuance of safety in the air that the present technical and administrative ability is not warped or varied.

If I may elaborate on these points in the few more minutes at my disposal, I would say that nothing does more harm to aviation than the publicity given to accidents in which a fire occurs: Most passengers in an aircraft subconsciously remember the fact that there are so many gallons of highly-inflammable spirit in their immediate vicinity, and so long as we are compelled to rely upon highly-inflammable fuel the risk of fire following an accident will be abnormal.

The advantages of a heavy-oil compression ignition engine are too obvious to need elaboration if that engine can be produced to operate efficiently at an economic figure.

Experience has shown that wherever the human element enters into the control of any means of transportation, the accident statistics vary in almost direct ratio to the proportion of the control which the human element exercises.

Any device, therefore, which relieves the crew of responsibility, or minimises the consequence of error of judgment, should automatically decrease the percentage of accidents.

We are all faced with the fact that we shall have to go on flying, in this country, in periods of bad visibility, and I am personally concerned at the increase in the risk of collision.

Cabin machines, when flying through rain or fog, invariably have a much reduced visibility. In addition, windscreens are liable to internal fogging and external clouding, with a certain amount of oil vapour and with possibly mud thrown on to the windscreen in taking off, the visibility tends to become less than normal safety requirements allow.

I think it should be possible for a pilot to get a good view in bad weather through open windows, without having his head blown off. I lay great stress on this point because the result of collision is especially serious in aviation.

I think there is very little chance of escape for passengers in a collision, and the risk is inclined to be greater owing to the prevailing laxity in observing the rules and regulations laid down for aerial navigation.

In some part this is due to the fact that present air navigation regulations are obsolete and often impracticable for the pilot to comply with. It is high time that international regulations were completely overhauled and revised, preferably by men who possess a practical knowledge of air navigation and its requirements. It is not sufficient to leave the re-drafting entirely to members of the legal profession.

The impracticability of certain of the rules has led to a widespread toleration of breaches, both at airports and on air routes. Whilst the letter of the law may be difficult if not impossible to comply with, the constant disobedience of pilots to the spirit of the law is a serious matter and tends to give all users of the air and airports, especially newcomers, the idea that there is neither reason nor necessity for air navigation regulations. The effect of this, unless checked, will be deplorable.

I have one last suggestion, based on the fact that no matter what safety device and what improvement in design or inspection or flying control are

produced, the national standard of our airmanship and our position in aviation generally will ultimately be determined by the attitude of those engaged in it.

As a nation we have always prided ourselves upon our seamanship. It is a legitimate and hereditary right which has existed through the ages amongst all those engaged with the sea. I hope most sincerely that a national tradition of airmanship in this respect is communicating itself among us in civil aviation. If we can achieve in our efforts the same standard of craftsmanship and tradition that they have done in the Mercantile Marine, I feel that we shall ultimately bring our commercial aviation to the same standard of safety, efficiency, and world-wide repute.

Concluding Remarks

I am convinced that aviation in itself is not inherently dangerous despite anything which this paper may have indicated to the contrary, but I do personally feel that the air, to an even greater extent than the sea, is terribly unforgiving of any carelessness, incapacity or neglect.

By " unforgiving," I mean that the results of carelessness, neglect or over-confidence are paid for more quickly and more dearly than in other forms of transport. Again I repeat, if the same keenness and knowledge and tradition which has already brought us in twenty years from our insignificant beginnings in the air to the present standard is utilised in preventing unnecessary accidents we can, with confidence, look forward to the time when Great Britain creates the same position for herself in the air as she has done on the sea.

In conclusion, I should like to express my very sincere thanks for the able and courteous assistance I have had from the Accidents Department and the Statistics Branch of the Air Ministry, and from my colleagues, without whose co-operation the preparation of this paper would not have been possible.

Discussion

The President : He congratulated Captain Lamplugh upon the fact that the lecture had drawn the largest audience that he (the President) had ever seen at a meeting of the Society. Whether or not the close study of accidents was inspired by the desire to avoid them he did not know, but the attendance did provide evidence of the confidence which the members of the Society had in the lecturer as a master of his subject.

The President commented upon the fact that accidents due to errors of judgment represented 50 per cent. of the total, and said he was impressed not so much by the figure itself as by Captain Lamplugh's attitude towards it. It appeared that he approved of the fact that this proportion was being reduced, and it had been shown that, of the countries referred to in the lecture, Germany was the only one in which the proportion of accidents due to errors of judgment was increasing. As one interested in the design and construction of aircraft, the President said he would like to see the figure increased to 100 per cent. ; then the aeroplane would be perfect.

Another matter which had impressed him was that high performance, in Captain Lamplugh's opinion—and his opinion could be accepted as fact—did not indicate liability to accident. It was also very interesting to note that the welded steel tubular fuselage was the safest of all, and particularly interesting to him because he had had a long struggle in introducing that particular type of structure into the military aircraft of the country ; he hoped that the Director of Technical Development, who was present at the meeting, had not missed the point.

Again, he had been very interested in Captain Lamplugh's remarks concerning eye-witnesses' accounts of aircraft accidents, because he had heard very unreliable evidence from eye-witnesses, and had had one particularly striking

experience in this connection. On the occasion in question he had witnessed an unfortunate accident due to a structural failure when in the air. When the machine was at a height of a few hundred feet from the ground the wings had parted; he was probably nearer to it than was anyone else at the time, and was actually looking at the machine. One's instinct in such an event was to avoid looking at it, but, as a designer, he had taken particular note of what had happened from the time the wings had parted until the machine had struck the ground. The very first person he had spoken to afterwards was a man for whose judgment on every technical question he had the greatest respect, but that man had totally disagreed with him.

Finally, the President said that the country was likely to have to face an era of very severe economy, and on behalf of the Society particularly he endorsed Captain Lamplugh's hope that that era of economy would not hit the Air Ministry, and particularly those departments which were responsible for safety in civil aviation.

Colonel SHELMERDINE (Director of Civil Aviation): He associated himself heartily with the President's remarks concerning the value of the lecture. The subject might be depressing but it was one that must be studied if they were to increase the safety of flying. Discussing the personal element, he asked for Captain Lamplugh's opinion as to whether the existing arrangements for the medical examination of pilots were satisfactory in every way. He also asked Captain Lamplugh to enlarge upon his criticisms of the international air regulations as they affected pilots. Colonel Shelmerdine expressed entire agreement with Captain Lamplugh's remarks concerning the potential and increasing danger of high-tension overhead cables. The matter was engaging attention at the Air Ministry continually, and it was hoped that it would be possible to evolve satisfactory means of marking and lighting such cables, at any rate within the vicinity of aerodromes and on the main air routes.

Colonel BARRETT-LENARD (Director of Imperial Airways): There were enormous difficulties in presenting the facts in such a form as to render them a reliable guide for the purpose of making comparisons. In order to explain the facts, the percentages and averages, Captain Lamplugh had included accidents and methods of description in other countries, and he had pointed out the difficulties of the comparative method. By inference, therefore, he had invited them not to lay too much stress on the resultant percentages in particular or figures in general. In spite of the difficulties, however, Captain Lamplugh had drawn attention to many causes of accidents and means of avoiding them if they were avoidable at all. Reference had been made to the presence of cows on aerodromes, but one did not imagine that anything the Director of Civil Aviation could do would prevent cows getting on to aerodromes. But there were many comforting reflections in the lecture, as, for instance, that British airframes, from the point of view of construction, left nothing to be desired. That accidents due to failure of engines were infrequent. That the standard of pilotage achieved by British professional pilots was very high. It was stated that errors of judgment became less frequent with greater experience, and one would be astounded to hear that some of the pilots who were so well known, and who had been flying longest, were even guilty of errors of judgment. Moreover, they could benefit from experience as much in flying as in anything else, as had been demonstrated; they were applying that experience to the development of flying operations and material, and it could be said that improvement was very marked. He congratulated Captain Lamplugh upon the suggestions he had made for effecting further improvement, and expressed the hope that, as to the part taken in aviation by the Air Ministry, they should leave well alone. He was glad that Captain Lamplugh had lifted the veil a little with regard to the methods of the Accident Department of the Air Ministry. His own impression was that the Head of that Department was a magician, of sorts; certainly it seemed that his eyes had the quality of X-rays.

Air-Commodore H. M. CAVE-BROWNE-CAVE (Director of Technical Development, Air Ministry): With reference to the President's remarks on the welded tubular steel type of fuselage, he hoped it was not assumed that the authorities disapproved of it. They did approve it frequently, but he suggested that to study its behaviour in a crash was not the best way of judging a fuselage. There were many other important considerations.

Mr. BRAMSON (Fellow, and Member of Council): It was not very clear, from the lecture, what rôle had been played in the past by power plant failures in accidents of which they were either the primary or the secondary cause. In that connection one felt that examinations should be made not only in cases where such failures had resulted in accidents, but also in cases where accidents had been avoided. Frequently, when engine failure occurred, it was by the merest chance that it did not lead to an accident; for example, the chance of a field being within reach of the machine when the engine failure occurred. An engine failure was equally important, whether or not the pilot of the machine succeeded in making a forced landing, and it was always a potential source of danger.

Captain Lamplugh's interesting and authoritative lecture, continued Mr. Bramson, provided a suitable opportunity for raising the question as to whether the reports of the Inspector of Accidents should be allowed to remain secret. There was one good purpose, and one only, that an aircraft accident could serve, namely, that of enabling those engaged in aeronautics to draw the appropriate lessons and act upon them, and it seemed to him to be utterly absurd that that purpose should be almost entirely defeated by secrecy. The very strong opposition to publication seemed to be based on confused thinking, possibly encouraged by vested interests. The alleged reasons advanced for secrecy were (1) respect for the dead and consideration for their families; (2) anxiety lest an erroneous conclusion might unjustly harm the manufacturer; and (3) the desirability of ensuring that the investigator was unhampered by outside considerations. He would endeavour to tear those arguments to pieces. In the first place, the so-called respect for the dead, in the sense of pretending that they could have done no wrong, was a sentimental convention which was itself practically dead. Mr. C. G. Grey had done something towards killing it. If he (Mr. Bramson) were to be killed whilst flying, the only redeeming feature from his own and his family's point of view would be the knowledge that the accident, by reason of the lessons it would teach, would contribute to the safety of flying in the future, and that would be possible only if the true cause were made generally known. If the cause were carelessness or incompetence, then it should be made known in order to ensure that the accident was not attributed to wrong causes. The so-called respect deprived a man's very death of the one feature which was of social value. The second argument—that of anxiety lest an erroneous conclusion might unjustly harm the manufacturer—hardly deserved to be called an argument. By common consent, the percentage of wrong conclusions arrived at by that highly experienced official, the Inspector of Accidents, must be negligibly small. Must British aviation forego the advantage of that immensely valuable and costly fund of accumulated knowledge contained in the records of civil aviation accident investigations just because a manufacturer *might* otherwise suffer at some time an undeserved slight? It seemed to him that when there was, or might be, conflict between public and private interest, it was right, at any rate from a Government Department, to give priority to the public interest. The third argument—that the investigator should be unhampered—was what psychologists would call a "rationalisation." Had anybody ever heard of a judge being hampered by fear of hurting anybody's feelings? The Inspector of Accidents was a judge, and Mr. Bramson expressed the conviction that the Inspector would do his duty with no more fear or favour than would be exercised by any other British judge, whether his finding were to be secret or otherwise.

The arguments for publication were almost childishly obvious. The reports of the Inspector of Accidents, which were growing almost daily in volume and

importance, constituted a most powerful instrument for progress towards ensuring safety, and had cost an immeasurable price in lives and material. They represented perhaps the most dearly bought collection of "experimental" data in the country, and had been paid for not by the Air Ministry or by aircraft manufacturers, but by hundreds of private individuals. Therefore, those reports should not be monopolised or kept secret by the Air Ministry; they should in all decency be public property.

Mr. C. G. GREY (Editor, *Aeroplane*): Discussing errors of judgment, he assumed for the purposes of argument that there were two aeroplanes of practically equal performance, one of which would stall and get out of control at 45 m.p.h., whereas the other would still be under control at, say, 35 m.p.h. If the man who was flying the first aeroplane stalled it and broke his neck, together with those of his passengers, he asked, where was the error of judgment? Was it in stalling the machine, or in flying it, or was the error of judgment the error of the designer who knew so little about aeronautics as to design an aeroplane which stalled at 45 m.p.h.?

Captain FERGUSON: He urged that the training of pilots should include more instruction in navigation. In his experience as an instructor a large number of persons, when learning to fly, got into difficulties immediately they lost sight of the surroundings with which they were familiar: often they lost their bearings, and in trying to find out where they were possibly landed in a field and smashed the machine or damaged the undercarriage. This might be classed under the heading of error of judgment, but if it was included under the heading of navigation it would increase this latter percentage and reduce the percentage under the heading of error of judgment. In the training of pilots we were concentrating upon teaching them how to fly round an aerodrome and to land, but were not paying sufficient attention to instruction in navigation, or in other words, how to make use of flying after they had learnt how to fly. He was of the opinion that if more attention was given to teaching pilots how to find their way about, the number of accidents occurring would be reduced very considerably, as not only would pilots learn how to use their instruments, but also to make use of meteorological information now readily obtainable, thanks to the excellent facilities provided.

Mr. C. C. WALKER (Fellow): He suggested that the statistics given of types of accidents would have been even more illuminating if they had been related to the mileage flown instead of being expressed as percentages. It was interesting for those connected with the design of aircraft to ask themselves to what extent the designer could contribute to the reduction of accidents. In this connection he had the idea that if aircraft were made very much stronger than at present, in order to eliminate any possibilty of main structural failure, the exuberant pilot would do inverted loops out of terminal dives and so live up to the new qualities of the machine. Again, if landing speeds were reduced to 20 m.p.h., pilots would try to land under conditions they would not contemplate at present. So that, with the improved machines, the pilot would still run approximately the same amount of risk as at present. Of course, Mr. Walker excluded the regular air line pilots from these considerations. Enlarging upon his argument, he said that it would be very difficult to design a safe motor car with a view to preventing accidents on the road, for exactly the same reason, that accidents were nearly always operational phenomena unconnected with the nature of the vehicle. For example, when four-wheel brakes were introduced, the motor drivers did not use them in a manner which would ensure greater safety on the road, but merely applied them later than they would have applied the brakes used previously. Therefore, Mr. Walker emphasised the point made by Captain Lamplugh, that the reduction of accidents must be effected by greater care and by the better use of experience, and that this was by far the most important method of increasing safety.

Colonel PICKARD (Secretary, National Safety First Association): Many of the deductions made in the course of the lecture applied very closely to other types of accidents in which he was interested. For example, experience showed that Captain Lamplugh's remarks concerning the ages of those who met with accidents while flying applied also to road accidents. Emphasising particularly the importance of the human factor in regard to accidents, he said that Captain Lamplugh had stated, in regard to aircraft accidents, that the human factor was 50 per cent. in one case and 70 per cent. in another. More than 80 per cent. of road accidents, however, were due to human failure, and 75 per cent. of industrial accidents were due to human and not mechanical failures. He suggested that the general public were also in need of further instruction on safety generally, for they had a wholly distorted perspective. This he attributed partly to the fact that, although there were half a million industrial accidents in the country per annum, those accidents were not regarded by the newspapers as news; the 200,000 road accidents which occurred in the country per annum were only fairly good news, but an air crash provided very good news and was usually the subject of large headlines. He hoped to see a great accession to the ranks of aviators. In his view there was no finer training for the younger generation than that of learning to fly, for it developed a quick eye and the ability to deal correctly with emergencies, whilst appreciating dangers. He would like to see the flying organisations educating the public on much the same lines as industry, on the one hand, and the motoring interests, on the other, had helped to educate the public, with useful results.

Major MAYO (Fellow): He emphasised the point made by the President, that the analysis of accidents on a percentage basis was apt to be misleading. In particular, as the President had rightly pointed out, it was most desirable that the percentage for errors of judgment should rise steadily. He would have thought that more than 80 per cent. of motoring accidents were due to errors of judgment, and was going to have suggested a figure of about 99 per cent.; but, at any rate, the percentage was very high and it provided a clear indication that a very high standard of safety had been reached in road vehicles. Errors of judgment could not be altogether eliminated, but it could be said with certainty that by the time the percentage of flying accidents due to errors of judgment has risen to 80, the total number of accidents per flying hour will have been reduced very considerably.

Major Mayo expressed cordial agreement with Mr. Bramson's plea for the publication of data concerning accidents, for he had always felt that it was almost a tragedy that the exceedingly valuable lessons which could be derived from the investigations of past accidents were lost to the public and to the world of aviation. He had often argued the matter but had never yet heard a really valid reason why the reports of the Inspector of Accidents on civil aircraft accidents should not be published. Major accidents received far more than their proper share of publicity, and these were the very accidents which were selected for further publicity because they were the subjects of public inquiries. In the case of a public inquiry the whole of the evidence was broadcast and the occurrence of the accident was rubbed in to the general public. What was really wanted was that the findings of the Inspector of Accidents should be made available to the public. If that principle were adopted it could be extended even to major accidents, so that there would be no need for elaborate public inquiries, but the public would be informed of the facts and enabled to benefit by the lessons to be learned therefrom.

The importance of ensuring a good field of view although mentioned in the lecture, had not been emphasised as strongly as might have been expected. He thought that the poor field of view afforded in the majority of aircraft was the primary cause of a large number of accidents. In the case of many accidents attributed to error of judgment on the part of the pilot, careful examination of the circumstances would show that the restricted field of view provided for the

pilot had been at least a contributory, if not a primary, cause. Ground accidents were very largely due to the pilot being unable to see properly. It seemed to him that in the long run this would be one of the most important factors in connection with the safety of flying. Nearly all the main causes of accidents at the present time could be and would be eliminated or greatly reduced, and as a consequence there would be a very great increase in flying. A result of that increase in flying would be a serious increase in the risk of collision. As Captain Lamplugh had said, they could not alter weather conditions, and weather conditions frequently made visibility bad. In order to avoid collisions as far as possible we must ensure that machines were constructed so that the pilot should at least have an uninterrupted view. It seemed that they were rapidly approaching the stage at which some definite control ought to be exercised in this matter. An aircraft from which the pilot's view was bad constituted a menace not only to itself and its passengers, but also to every other aircraft flying; therefore, there ought to be, and there would have to be, a definite control and the enforcement of a certain standard for the pilot's field of view.

Communicated.—In his summary of possible remedies Captain Lamplugh has referred to the importance of air traffic control at aerodromes and along traffic routes. There is one aspect of this problem which deserves special attention, namely, the difficulty of controlling civil aircraft other than those engaged in regular air transport. Every regular transport aircraft is, of course, provided with a radio installation by means of which communication can be maintained with the pilot. In this way very effective control over the movements of such aircraft along an air route and at aerodromes can be exercised. In the case of an ordinary civil aircraft, however, there is no radio installation and it is thus impossible to convey signals to the pilot. As air traffic develops and the need for effective control increases, it will become increasingly important that every aircraft making use of a regular air route shall be provided with an effective means of communication with the ground and with other aircraft. There is, of course, an essential difference between shipping and air traffic in regard to the risk of collision. All ships of appreciable size are subject to effective control, particularly when entering or leaving port. Small craft are not under control to the same extent, but if a small craft fails to observe the regulations it is not likely to do much harm to the larger ships. In the case of air traffic the position is quite different. A large air liner may observe all regulations and comply fully with any special instructions communicated to it by wireless, but if a small private aircraft should, through neglect of regulations or lack of knowledge of the movements of other aircraft, get in the way it may easily cause disaster to the air liner. There is thus already a strong case for making compulsory the carrying of a satisfactory radio installation, but as time goes on it will be imperative to introduce a regulation to this effect, or alternatively to debar aircraft not so equipped from flying in the region of regular air routes. In the meantime every encouragement should be given to private owners to equip their aircraft with radio receiving sets, and to those willing to establish transmitting stations for the communication of meteorological and other information. Many accidents to private aircraft could have been avoided in the past if the pilot had been able to receive information as to weather conditions.

Mr. R. A. C. BRIE: He would like to refer to the autogiro as a type of aircraft which offered a greater degree of safety than ordinary aeroplanes, because it helped to eliminate the human element as a factor in accident causation. He personally did not consider that flying, as such, was dangerous, but anything which increased safety by eliminating the human element would do much to encourage many more people to fly. Quite recently he had completed a tour with the autogiro, and had been amazed by the large number of people who, having seen it demonstrated, had said that that was just what they had been waiting for. There was an urge to fly even among people in whom one would not expect it, people who had reached a stage in life at which, it would be

expected, they would desire to keep one foot on the ground. Ladies and gentlemen of 50 years of age, or more, had said that they wanted to fly, and they wanted machines which would enable them to fly with less fear of hurting themselves. It was difficult to say, of course, whether or not that would be borne out by facts in the future, because there were no statistics on which to base the assumption, but he did feel that when the autogiro was on the market many people would feel that they could fly with greater safety. It was the fear of accident that prevented them flying, such fear being due to a great extent to the relatively high minimum speed at which the ordinary aeroplane had to be flown to remain under control.

Mr. MANNING (Fellow and Member of Council): Judging from the conversations he had had with members of the general public, they were more worried, in regard to aircraft, by the risks of fire than by any other factor. Incidentally, although the first experiments which had made possible the development of the aircraft Diesel engine had been carried out in this country, he believed that this was the only country in the world which had not an aeroplane flying with a Diesel engine. He asked what was the effect of the position of the exhaust pipe, the inverted engines, and the position of the petrol tank, upon the risk of fire in the event of a crash, and what was the effect of a metal fuselage in the case of fire; also, whether the accident statistics gave any indication of the effect of wing slots upon the number of accidents?

REPLY TO DISCUSSION

The President.—I entirely agree with the suggestion made by the President and other members to the effect that any increase in the percentage of accidents due to personal errors marks a corresponding improvement in construction and design, provided that the ratio of accidents to hours flown does not also increase.

My attitude in the matter is not so much one of alarm at the percentage therefore as of alarm at the cost which that percentage represents. In actual direct damage alone personal errors in Europe have cost a quarter of a million pounds a year for the last three years, and it is this figure rather than the percentage figure which I desired to emphasise.

It is the ultimate net cost that is retarding civil aviation whether in operation charges or in accidents, and here surely we are able to effect a very big saving.

Colonel Shelmerdine, D.C.A.—The disadvantage of the present system of medical examination for A. license pilots is two-fold in character. In the first place the examination is carried out by the candidates' own medical adviser. While this has certain advantages it is liable to lead to a lack of any fixed standard, especially bearing in mind that the private practitioner is liable to be biased to some extent in favour of the candidate. In the second place there is no periodical re-examination, with the result that many A. license pilots must be flying to-day who would not pass the requirements for a new license.

It might be said that unless a pilot is to fly for hire or reward there is no justification for any particular standard of physical fitness, and I think that this argument is unsound because the qualified A. pilots can carry passengers and they have to fly over property belonging to the public, who are entitled to some measure of protection. It is impossible to say whether many A. license pilots are still physically fit and as even the A. license pilot is liable to physical deterioration with advancing years some measure of check on physical ability must be utilised.

As regards the International Air Regulations, I consider that they require complete revision, but the following may be cited as specific examples of regulations which (whether desirable or not) are consistently disregarded, or are incapable of due observance, facts which tend to undermine the usefulness of the regulations as a whole.

(*a*) An aircraft must not pass another at a distance of less than 600 feet.
(*b*) An aircraft must fly for at least 500 yards in a straight line from the boundary of the aerodrome after taking-off and must then turn to the left.
(*c*) "Circuit Laws" must be obeyed at a distance between 500 and 3,500 yards from the nearest point of the aerodrome at all heights below 6,000 feet.
(*d*) No aerobatics are permitted within 4,000 yards from the nearest point of the aerodrome except at a height above 6,000 feet.
(*e*) The rules as to aerodrome zones.

Air Commodore Cave-Browne-Cave.—Granted that every type of fuselage construction approved by the A.I.D. is aerodynamically sound and that the cost of construction and maintenance of a welded steel type of fuselage is not appreciably greater than that of any other type, what better standard of value can be set up than the comparative safety which this type affords to its occupiers in an accident?

From the point of view of cost of production the human element in the aircraft is the most costly of its individual components. Surely, therefore, other things being equal, a construction which minimises damage to occupants is an economy, if not a necessity.

Both Mr. Bramson and Major Mayo raise the same point with regard to lack of publication of data in connection with accidents.

The present position is as follows:—

The Inspector of Accidents reports to the Secretary of the Air Ministry on his investigation. While this report is in itself not published, the conclusions arrived at by the Inspector of Accidents can be obtained by any interested party on application to the Air Ministry.

I am not prepared to argue as to whether the full report or only the conclusions should be published, but after all said and done, conclusions are the vital matters and it would prevent unnecessary argument to publish only the conclusions.

It should be borne in mind that the causes of the majority of accidents are fairly obvious and do not require detailed investigation and the findings of the few which are doubtful can be obtained.

Mr. Grey.—Mr. Grey has himself been a most persistent advocate of higher cruising speeds which, in the light of present aerodynamic knowledge, involve higher landing speeds.

Even the Editor of *The Aeroplane* cannot both have his cake and eat it and he must be as well aware as anyone of the aerodynamic value of the word "compromise." To follow Mr. Grey's argument to its logical conclusion would involve the decision that every accident is due to an error of judgment on the part of the pilot in even flying at all!

Mr. C. C. Walker.—I quite appreciate the point taken by Mr. Walker as to the dangerous comparisons between percentage statistics. Even if it were possible to give the percentages on a mileage basis, however, they would still be apt to mislead, because such matters as the type of aircraft, type of pilot, the weather and the route, to name only a few points, are still vital matters affecting the accuracy of the statistics for the purposes of comparison.

Upon the question of safety devices, Mr. Walker's argument is effective, but I venture to think fallacious. Where the complete elimination of the personal element can be secured all experience tends to show that the risk of accident decreases almost to vanishing point Where the personal element is only partially eliminated it is quite true that the damage caused by personal errors may remain the same to outward appearances, because the pilot takes advantage of the greater scope given to him. Nevertheless the usefulness of the aircraft is, generally speaking, increased because the pilot can achieve more for the same

number of accidents, whether such achievement is in the nature of greater speed, greater distance covered or ability to land and take-off closer to his objective.

Major Mayo.—The first two points raised by Major Mayo are already dealt with in my replies to Colonel Shelmerdine and Mr. Bramson. Upon the question of visibility it must be appreciated that, as in all aspects of aircraft design, the matter is one of compromise. To some extent it will perhaps always be necessary to sacrifice the view of the pilot to his protection from the elements and to the performance required from the aircraft. There will always be a blind spot somewhere, but the most important thing is that the pilot's view straight ahead and through an angle of at least 90° to either side should be as unrestricted as possible. We have not yet reached the point where the single-engined tractor type can be altogether discarded, but a good deal can be done and is being done to improve the pilot's view by the use of inverted engines and seats which can be raised or lowered at will.

It is not practicable at present to insist upon the carrying of radio telephony by all aircraft. Meanwhile, however, much could be done to avoid the risk of collisions in the air by a stricter observance of the Air Navigation Regulations. The necessity for the revision of these and for their subsequent enforcement has been dealt with in the reply to Colonel Shelmerdine.

Mr. Manning.—I agree that the positions of exhaust pipe, fuel tanks and inverted engines are all of prime importance.

One has had a case of a centre section tank in an early type machine being positioned by piano wire, and in every case when this type spun into the ground the tank broke clean away from the aircraft. A modification was introduced by fitting the tank by means of fish plates, with a result that on many occasions if the modified type spun into the ground a fire occurred.

These matters can only be dealt with by criticism in design and by continually stressing the importance of fire protection while we still use highly inflammable fuel.

Most British manufacturers give this matter attention.

AERONAUTICAL RESEARCH COMMITTEE

AN AUTOMATIC VARIABLE PITCH AIRSCREW *

BY

H. C. H. TOWNEND, B.Sc.

NOTE.—After this paper was written (January, 1930) the writer found records of proposals for airscrews working on very similar lines to those suggested here. As these earlier attempts at a solution of the variable pitch airscrew problem did not appear to have been adopted in practice, it was thought that they were probably unsuccessful for some mechanical reason, and no further work was undertaken.

Recently, however, an account has been published† of an automatic variable pitch airscrew working on exactly the same principle as that proposed here, and in view of the fact that it has been tested in flight it is thought that the wind tunnel work described below, which was carried out at the National Physical Laboratory, may be of interest. As an appendix to the paper, an abstract is given of the French account of the full-scale screw mentioned above.

January, 1930.

Summary

Some wind tunnel experiments have been made on a variable pitch airscrew which shall change its pitch automatically as V/nD changes. The change in pitch is operated by the resultant effect of centrifugal and aerodynamic forces.

Reduction in air density, *e.g.*, due to increase in height, causes an increase in pitch.

In the event of engine failure the blades assume the position of minimum drag.

A tentative design for a model screw, together with tests thereon, are described, and it appears that if the friction in the bearings about which the change in pitch occurs can be made reasonably small, it should be possible to construct a satisfactory full-scale screw.

The following is a description of a suggested design for a variable pitch airscrew which will adjust its pitch automatically to approximately the best efficiency, corresponding to the particular value of V/nD at which the machine is flying.

The design involves the use of blades which are pivoted freely to the airscrew boss, not, as has often been proposed, with the pivot axis at right angles, or nearly so, to the axis of the blade but making a comparatively small angle with it (of the order of 15°). Only a small fraction of the centrifugal force comes on the pivots themselves.

* This work was carried out at the National Physical Laboratory. Permission to communicate it was kindly given by the Aeronautical Research Committee.

† Les helices a pas Variable. G. Leparmentier. Premier Congres International de la Securete Aerienne. Paris, December, 1930.

The object of introducing a pivot axis inclined in this way is to provide a means whereby a change in the thrust on the blades may be made to produce a change in the pitch angle of the blades. A photograph and a sketch of the screw are shown in Fig. 1.

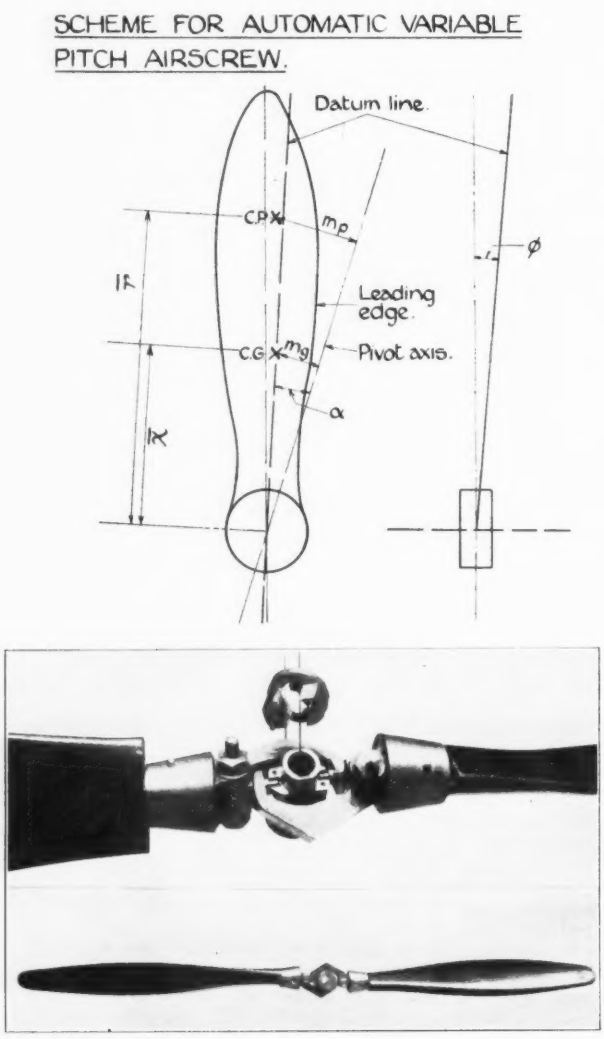

FIG. 1.

Principle of the Screw

For the purpose of description the case will be considered of an airscrew running at constant *rotational* speed. Under these circumstances the centrifugal force on a blade will be constant and, starting with the condition thrust = 0

(high V) and neglecting the other aerodynamic force components, the blade will describe such a path about the axis of rotation, that the resultant moment of the forces about the pivot axis will be zero. Calling the plane in which the pivot axis lies the " plane of rotation," it is evident that some line fixed in the blade will be in this plane at zero thrust. This line will be called the " datum line " for the blade.

As the forward speed V is reduced the blade develops a thrust and the datum line will move forward out of the plane of rotation (as defined above) until the moment of the centrifugal force about the pivot axis balances the moment of the thrust. In doing so, the consequent rotation about the pivot axis will be accompanied by a corresponding rotation of the blade about its length giving rise to a change in the pitch of the screw.

This change will proceed progressively as the speed V falls, down to " static " ($V=0$) where the thrust will reach its maximum.

By a suitable choice of the value of the angle α between the pivot axis and the blade, a given change in pitch may be made to result from any given change in thrust.

In order to design a screw on these lines which should have desirable pitch characteristics over a wide range of V/nD, some very rough calculations were made based on results published in R. & M. 829* of a series of experiments on a screw having blades the pitch of which was varied over a range of blade angle (θ).

The screw in question was the metal two-bladed screw No. 3 of the Family of Airscrews, the normal pitch diameter ratio of which was $P/D=0.7$ when the blades were set to give constant geometrical pitch along the blade.

In R. & M. 829 the performance of this screw is given for changes in pitch setting, $\Delta\theta$, of $-9.25°$, $-4.5°$, $0°$, $6.5°$, $12°$, $16°$ and $19°$ from the constant pitch position.

The method of design adopted was to select the value of $\Delta\theta$ which gave the best efficiency at high V/nD, and take the corresponding thrust and torque coefficients at the V/nD of maximum efficiency for that value of $\Delta\theta$. Then to assume the same torque coefficient at static and to find, by plotting k_Q (static) against $\Delta\theta$, the necessary value of $\Delta\theta$. The difference in these values of $\Delta\theta$ gave the change in pitch required from static to maximum efficiency.

The corresponding values of the thrust for the same two conditions gave the change in thrust available for producing the desired change in θ. The condition of zero resultant moment about the pivot axis together with the geometrical relation between the angle α and the distance of the c.g. from the plane of rotation then enabled α to be found for any blade for which the weight and positions of the centres of pressure and gravity were known.

Actually the equation of moments about the pivot axis should include terms involving the torque and the pitching moment on the blade sections and also a term representing the friction of the bearings. The latter term may be of considerable importance in the design. For the purpose of this rough estimate it was assumed that the moment of the centrifugal force about the pivot was the same as that obtained by considering the mass to be concentrated at the c.g., though the actual distribution of mass in the blade should be allowed for in a proper design since the screw is not a rigid body, and has no simple two-dimensional equivalent.

Each of these approximations leads to an over estimate of the change in pitch to be expected.

Representing quantities at maximum efficiency with the suffix o and those at static with suffix s,

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* R. & M. 829. Experiments with a family of airscrews, including the effect of tractor and pusher bodies. Part I.—Fage, Lock, Howard and Bateman.

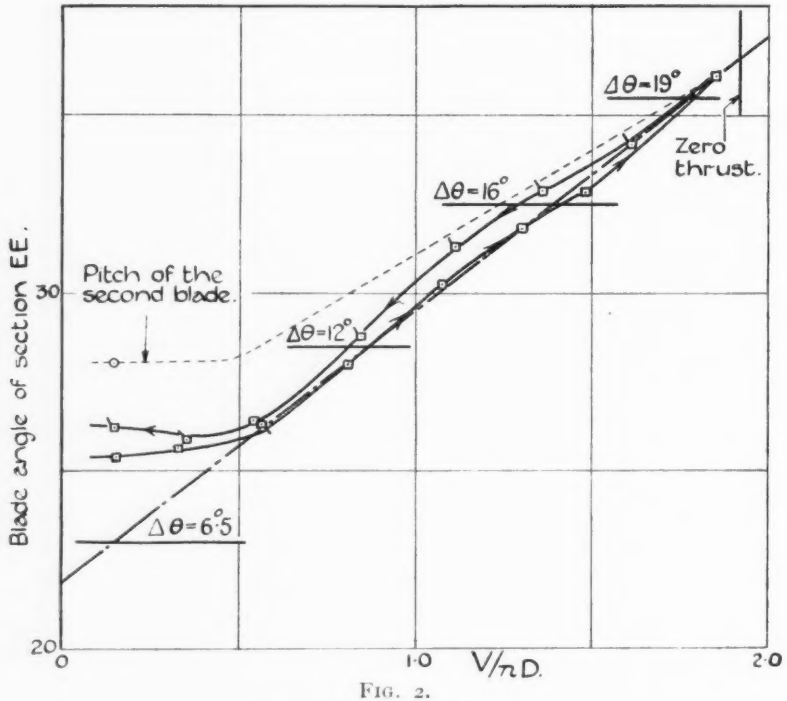


FIG. 2.

VARIABLE PITCH AIRSCREW.
OBSERVED CHANGE IN THE PITCH OF ONE BLADE.
$\Delta\theta$ = *angle by which the pitch exceeds that of two-blader No. 3 (R. & M. 829), for members of the family of variable pitch airscrews.*

Let t = thrust per blade.
w = weight per blade.
$\bar{x}$ = radius of c.g. of blade.
$\bar{r}$ = radius of c.p. of blade for thrust.
θ = pitch angle of blade.
ψ = angular displacement of c.g. about the pivot axis from its position at zero thrust.
ϕ = corresponding angular displacement of the c.g. about an axis through the shaft.
a = angle between the pivot axis and datum line at no thrust.
m_p = perpendicular distance from c.p. to pivot axis.
m_g = perpendicular distance from c.g. to pivot axis.

Then

Moment of thrust about pivot axis
$$= t m_p \cos\psi \text{ approx.}$$
Moment of centrifugal force about pivot axis
$$= (w/g)\,\omega^2 \bar{x} \sin\phi\; m_g \cos\psi$$
For equilibrium
$$t = (w/g)\,\omega^2 \bar{x} \sin\phi\; (m_g/m_p).$$

And since

$$\bar{x} \sin \phi = m_g \sin \psi \text{ and } m_g = \bar{x} \sin \alpha$$
$$\therefore \sin \phi = \sin \alpha \sin \psi$$
$$\text{and } t = (w/g)(2\pi n)^2 x (m_g/m_p) \sin \alpha \sin \psi$$

$(m_g/m_p) \sin \alpha$ is a function of α only, and is most easily obtained graphically, when the c.p., the c.g. and the airscrew shaft are not coplanar.

Also

$$t = \tfrac{1}{2} k_T \rho n^2 D^4$$
$$\therefore \sin \psi = A k_T / f(\alpha) \quad . \quad . \quad . \quad . \quad . \quad . \quad (1)$$
$$\text{where } A = \rho D^4 g / 8\pi^2 w x$$
$$\text{and } f(\alpha) = (m_g/m_p) \sin \alpha$$

For the airscrew tested in R. & M. 829 (two-bladed screw No. 3) the following conditions were assumed:—

(1) At maximum efficiency (= 89.5 per cent.)
$$\Delta\theta = +16^\circ$$
$$V/nD = 1.4$$
$$k_T = 0.0460$$
$$k_Q = 0.01145$$

(2) At static k_Q = the same (assumed) = 0.01145
giving $\Delta\theta = 3.3^\circ$
and $k_T = 0.1190$

So that $\theta_s - \theta_o = 16 - 3.3 = 12.7^\circ$ = change of pitch angle from maximum efficiency to static, and

$$\therefore \psi_s - \psi_o = 12.7/\cos \alpha \text{ approx.} \quad . \quad . \quad . \quad . \quad . \quad (2)$$

and

$$(k_t)_s/(k_t)_o = 0.1190/0.0460 = 2.59$$
$$= \sin \psi_s / \sin \psi_o \quad . \quad . \quad . \quad . \quad . \quad . \quad (3)$$

The airscrew blades used for testing out this form of variable pitch airscrew had the following constants:—

$$\left.\begin{array}{l} D = 3 \text{ feet} \\ w = 0.313 \text{lbs.} \\ \bar{x} = 0.646 \text{ feet} \end{array}\right\} \text{giving } A = 0.387.$$
$$\bar{r} = 1.05 \text{ feet (approx.)}$$

The positions of the c.p. and c.g. along the breadth of the blade were also found and their distances from the pivot axis m_g and m_p determined graphically for a few values of α near 15°.

First Approximation.—Assuming that $\cos \alpha = 1$, equations (2) and (3) give:—

$$\left.\begin{array}{l} \psi_s = 20.5^\circ \\ \psi_o = 7.8^\circ \end{array}\right\} \text{approx.}$$
$$\therefore \text{from (1) } f(\alpha) = A (k_{Ts}/\sin \psi_s) = 0.1315$$
$$\text{Also very roughly, } m_p/m_g = \bar{r}/\bar{x} = 1.625$$
$$\therefore \sin \alpha = 0.214$$
$$\alpha = 12.4^\circ$$
$$\therefore \cos \alpha = 0.977$$
$$\therefore \psi_s - \psi_o = 12.7/0.977 = 13^\circ$$

Second Approximation.—From (2) and (3) gives

$$\left.\begin{array}{l} \psi_s = 20.9^\circ \\ \psi_o = 7.9^\circ \end{array}\right\}$$
$$\therefore f(\alpha) = 0.129$$

and by plotting $f(\alpha)$ which is linear over the required range against α for the particular screw used this is found to correspond to

$$\alpha = 13.3^\circ.$$

The experimental model was made with wooden blades of the same shape and sections, etc., as those tested in R. & M. 829. It was made with the above value of a but variations in a were allowed for so that the best value could be found experimentally.

Estimate of Performance

The performance of the screw with $a = 13.3$ was estimated by finding the values of k_T which are necessary in order that the blade angles may take the

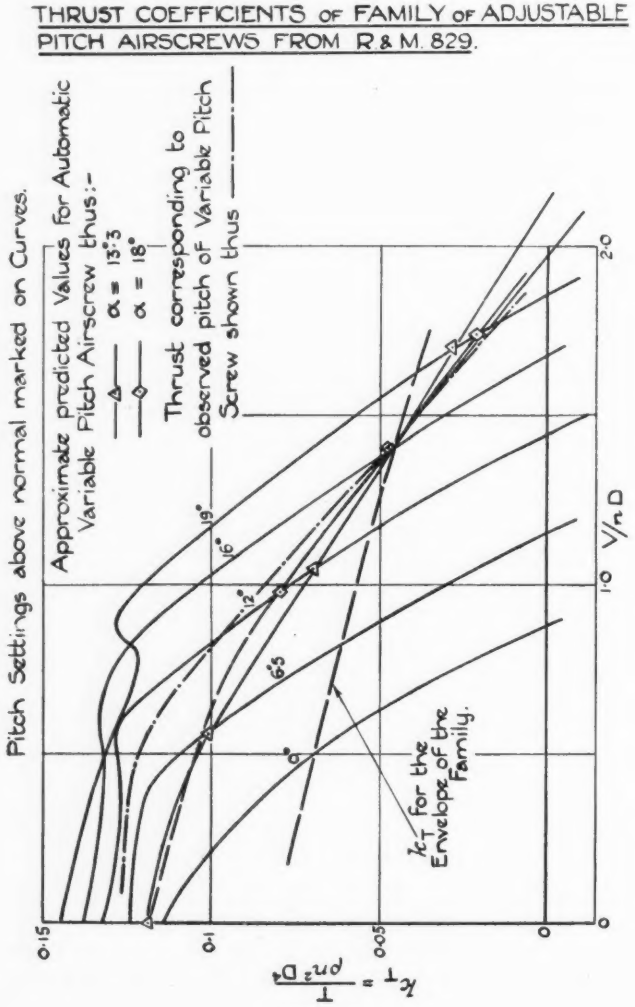


FIG. 3.

values corresponding to $\Delta\theta = 19,\ 16,\ 12,\ 6.5$, for which observations are available in R. & M. 829. The formula

$$\psi = \psi_0 + (16^\circ - \Delta\theta)/\cos\alpha$$

is used instead of (2).

The resulting values of k_T are marked on the appropriate members of the family of k_T curves in Fig. 3 and, at the corresponding values of V/nD, the torque coefficient and efficiency are shown in Figs. 4 and 5.

Other Values of α.—The calculations were repeated for one or two other values of α, $f(\alpha)$ being obtained graphically from the drawing of the screw blade.

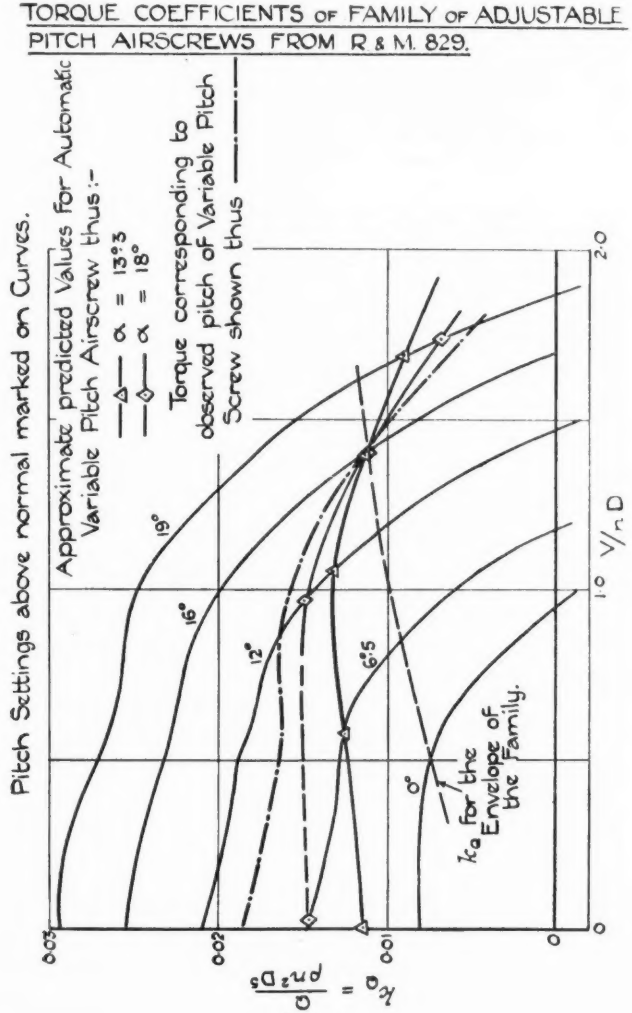


FIG. 4.

The curves for different values of a suggest that some choice in thrust and torque characteristics is available without much change being caused in the efficiency curves, which are all not far from the envelope of the family of original adjustable pitch screws.

Owing to the omission in the calculation of the torque term in the moment equation, however, which term appreciably limits the change in pitch, the range of characteristics available by changing a would not be as large as indicated in the figures.

All the efficiency curves fall below the envelope near $V/nD=0.8$, but this is inevitable if a reasonably high thrust and torque are to be developed even if the

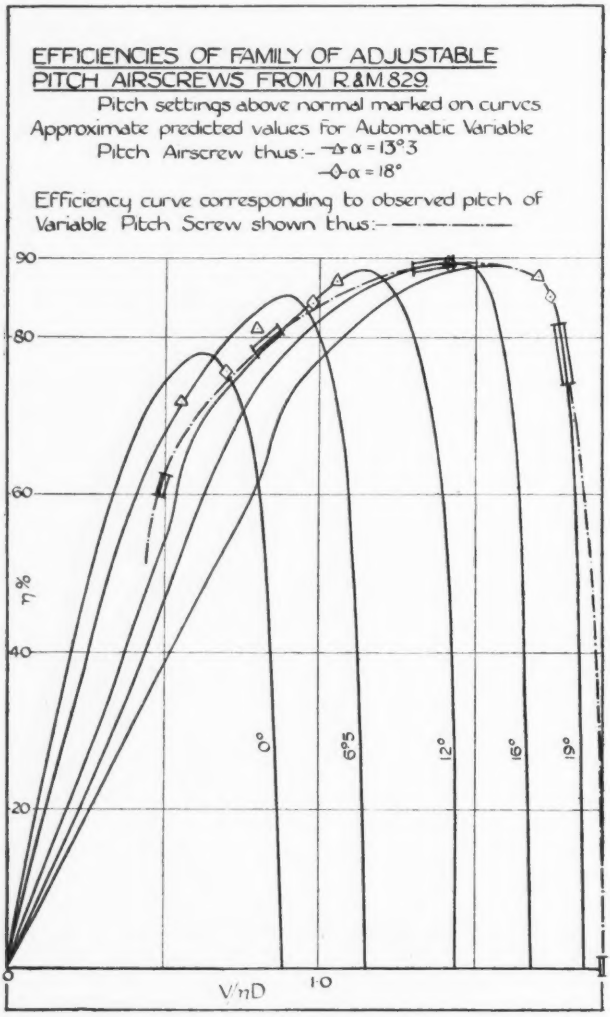


FIG. 5.

pitch were variable at will. The k_T and k_Q curves corresponding to the true envelope (shown dotted) show this at once.

Description of Tests

The screw designed on the above lines was made and experiments commenced in December, 1929. Wooden blades of identical form to those tested in the experiments of R. & M. 829 were employed. The details of the pivot are shown in the photograph. No attempt was made to design a bearing that could be used on full scale.

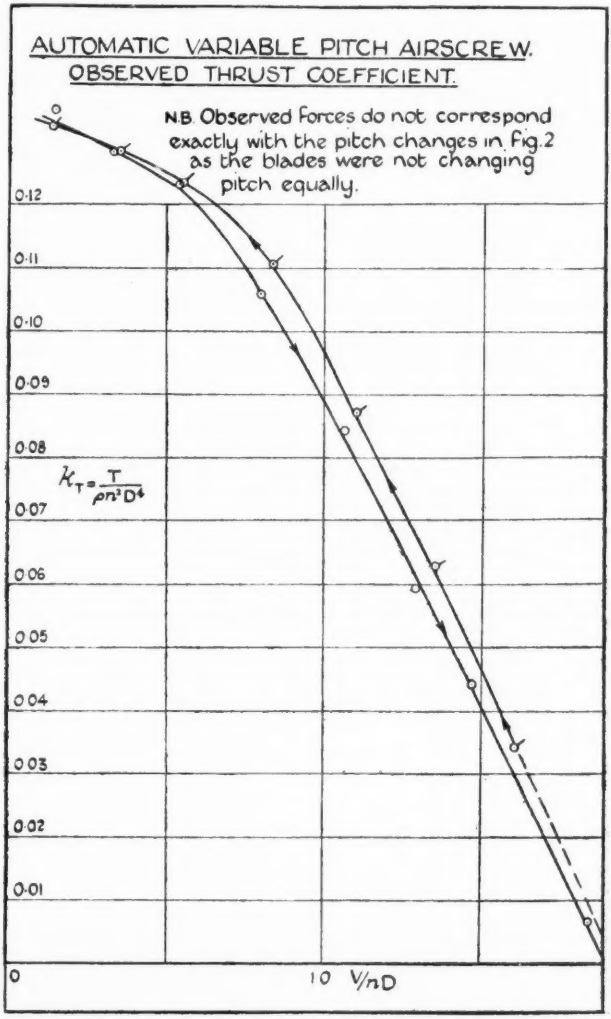


FIG. 6.

The best value of α was found to be about 11°, with the centre line of the blade intersecting the pivot axis at a distance of 1.2in. from the axis of the shaft.

The screw was mounted on the standard airscrew testing balances in a 7ft. tunnel and measurements of thrust and torque made over a range of V/nD from static to no thrust.

In addition a small mirror was attached to each blade for enabling the pitch angle of the blades to be measured as a function of V/nD. This quantity is perhaps the most important in these particular experiments as it enables the values of V/nD to be determined at which the variable pitch airscrew becomes

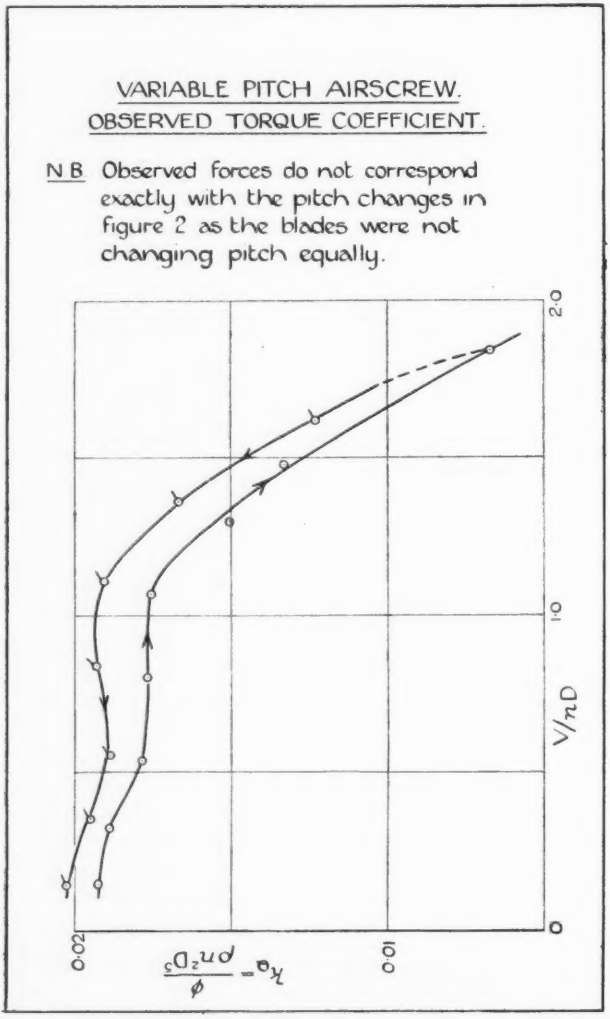


FIG. 7.

identical with the members of the family of adjustable pitch screws as given in R. & M. 829 (and plotted in Fig. 14 of R. & M. 892).

This method of comparison has the advantage that it eliminates any uncertainty due to the large boss correction applied to the results of R. & M. 829, or to the lack of any correction which should have been applied to the results given here. Further, it eliminates the error due to the observed fact that the two blades were not changing pitch to the same extent and which means that the observed forces do not correspond exactly to the observed pitch.

Results of Tests

The change in pitch experienced by *one* of the blades is shown in Fig. 2. The pitch angle of section EE (at radius of 0.75, the radius of the screw) is shown plotted against V/nD. On the same figure are shown the V/nD for zero thrust (*i.e.*, of both blades) and the pitch angles corresponding to the members of the family of adjustable screws. The points of intersection give the values of V/nD at which the screw has the same characteristics as the members of the family and by transferring these values of V/nD to the curves showing the thrust torque and efficiency of the family, the corresponding curves for the variable pitch screw are obtained. This has been done in Figs. 3, 4 and 5 which show the family of experimental curves obtained in R. & M. 829.

On the same figures are also shown the roughly calculated results as mentioned above, and also the results corresponding to the true envelope of the efficiency curves.

The forces actually observed on the variable pitch screw, without any allowance for boss correction (which would be small in any case) or for the fact that one of the blades was not giving such a large change in pitch as the other, are shown in Figs. 6 and 7.

It will be seen that the curves are double, a different curve being obtained with rising V/nD from that obtained with V/nD falling. This is due to a lag in pitch caused by friction in the pivots. As the centrifugal force on a blade was taken on one $\frac{1}{4}$in. ball, it is probable that most of the friction arose from the torque giving considerable journal friction on the sides of the pivots, which were rather roughly made. There was, in addition, considerable slack in the pivots, permitting a certain amount of motion parallel to the airscrew axis without causing the pitch to change. For all these reasons, therefore, the observed force measurements must not be regarded as the best which could be obtained even with this particular design which is in any case only a first approach to a solution.

The efficiency curves are shown in Figs. 8 and 9. In Fig. 8 the observed efficiency is shown for both rising and falling V/nD. Also the observed and theoretical efficiency envelopes from R. & M. 829 are given for comparison. These are somewhat uncertain at high values of V/nD on account of the large boss correction.

In order to cut out the boss correction as far as possible and to enable the shapes of the curves to be compared better, they have been replotted in Fig. 9 as η/η max. against V/nD.

Discussion of Results

The merits of the screw can best be judged from Fig. 5 in which the chain dotted curve shows the efficiency obtained by drawing a curve through one point on each member of the family of adjustable pitch screws from R. & M. 829, the points being determined from Fig. 2 by the process mentioned above. The predicted curve is also shown.

From Fig. 2 it will be noticed that although a range of pitch of about 11° was obtained from static to no thrust, the whole change occurred between V/nD

0.5 and 1.9, the pitch remaining constant from static to 0.5. If the straight part of the curve be produced down to static it would correspond to a change of 11.5° in pitch from static to $V/nD = 1.4$ which is the V/nD of maximum efficiency whereas the change designed for was 12.7°. Thus the screw behaves as though it had very nearly the desired rate of change over the important range of V/nD (*i.e.*, from 0.5 to 1.9) the whole failure to change pitch occurring below 0.5. Over the important range, therefore, the efficiency tends to approach the envelope fairly closely, whilst near static the thrust and torque tend to be high.

A curve is also shown in Fig. 2 showing the pitching behaviour of the other blade. This curve was only observed at its extreme ends and is also uncertain to

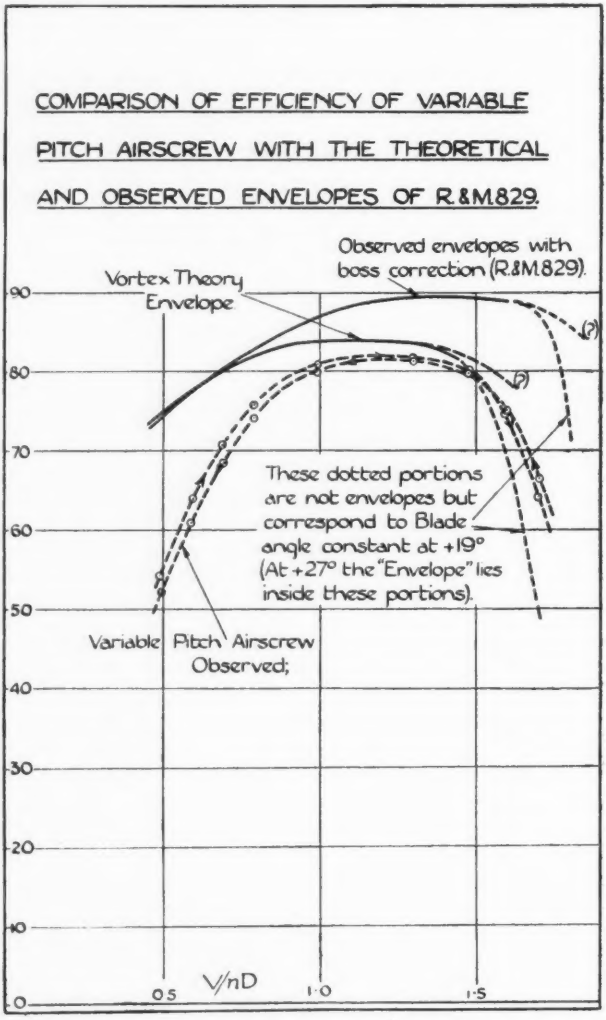


FIG. 8.

the extent of a constant, *i.e.*, the whole curve may be one or two degrees lower or higher. It shows the extent of the *change* in pitch on that blade however, and indicates the difference between the two blades. It is thus clear that the observed force measurements do not correspond with the observed pitch measurements, and this must be borne in mind when considering absolute efficiencies.

Conclusions

A few interesting features of this type of screw are collected below with some remarks on their bearings or design, etc.

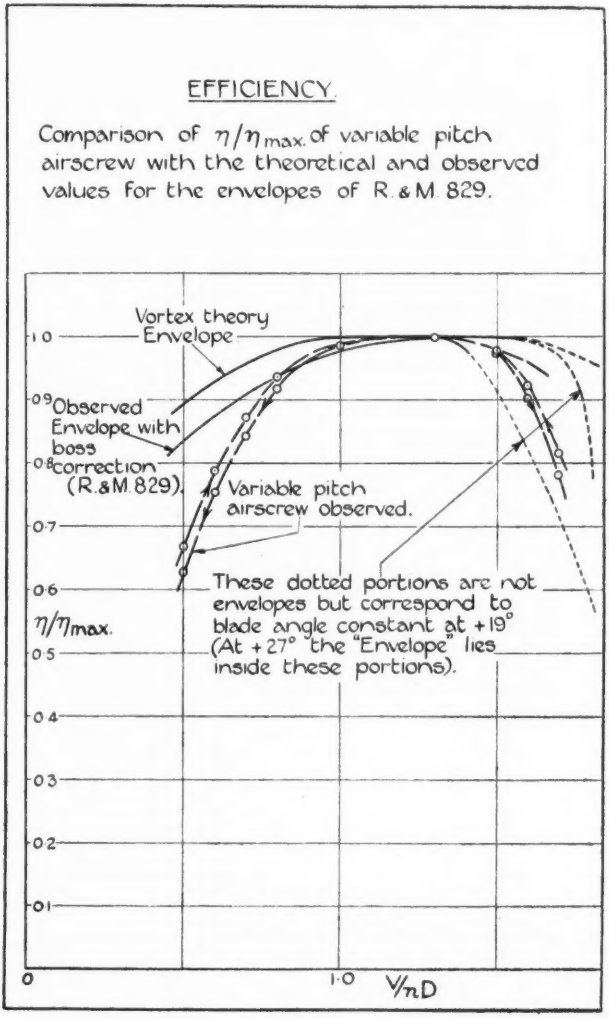


FIG. 9.

Since the centrifugal force, which tends to maintain a high pitch, varies as n^2, whilst the aerodynamic forces vary as ρn^2, it is evident that a reduction in air density will cause an increase in the pitch, *i.e.*, the pitch will increase with height.

The bending moment at the root of the blade due to thrust is zero for all pitches.

It is also possible that since the blade is staggered backwards (in the plane of rotation, viewed from the front) from a point a short distance from the axis of rotation, it may be possible to make the centrifugal force reduce the bending moment at the root due to the torque also.

In the case considered here the blade pivots had a common axis which was therefore necessarily parallel to the plane of rotation.

If separate pivots are used at a small distance apart it would be possible to incline the pivot axes to the plane of rotation and thereby to modify the manner in which the torque on the blade affects the pitch. For example, at a high thrust it would be possible to arrange that the resultant torque passed through the pivot axis and so had no moment about it, whilst at zero thrust, where the resultant torque would lie behind the pivot axis, and have a large moment arm, the moment would be small because the torque itself is small. By this means the torque term in the equation of moments about the pivot axis may be made relatively small over a good part of the range of pitch.

By manipulating the mass and thrust distributions along the blade (*i.e.*, the blade shape) and also the position and inclination of the pivots relative to the blades, both along and across the airscrew shaft it is possible to obtain screws which differ in their force characteristics whilst still adhering fairly closely to the envelope of the efficiency curves.

If sufficient angular motion about the pivots can be provided, the blades will, in the event of engine failure, automatically assume the position of minimum drag.

It will also be noticed that even if no stops are provided, the screw cannot, when at rest, move backwards or forwards through an angle greater than α (*i.e.*, about 12°).

During the experiments a close watch was kept for any signs of oscillation developing, but no tendency towards instability was observed. The speed at which the screw was run was not high (about 18 revs. per second) so that perhaps no trouble was to be anticipated, but the fact that the thrust moment is zero at the root would suggest that any natural frequencies would be higher than with rigid blades.

Probably the most critical factor entering into the design is that of friction in the pivots. If by using ball bearings for taking both the centrifugal force and aerodynamic forces this can be sufficiently reduced it would seem feasible to construct a full-scale screw which would change its pitch by the requisite amount. The vibration of the machine would materially help in this respect and in addition there is the periodicity in the torque, although this latter may introduce its own troubles by causing " snatch " in the pivots.

A further small periodic force arises from the fact that the effect of gravity on the blades causes a very slight inclination of the plane of rotation to the plane normal to the shaft.

If a given amount of friction is deliberately introduced into the pivots then the " lag " in pitch may be adjusted, and a certain amount of control of the pitch obtained. Thus, if at a given flight speed it is desired to increase the pitch slightly, it would only be necessary to switch off the engine suddenly and glide a short distance, thereby causing the pitch to increase, and then open the throttle gently again. The frictional lag will then maintain a higher pitch than that corresponding to zero thrust moment at the root. Conversely, the minimum

pitch will automatically occur if the machine is simply climbed steadily to its cruising condition.

APPENDIX

Abstract of an Account of Some Full Scale Tests by G. Leparmentier *

The airscrew was tested first in 1921 on a Breguet 14A2 and later on a Breguet 19A2, both fitted with superchargers.

AUTOMATIC VARIABLE PITCH AIRSCREW.
(G. Leparmentier)

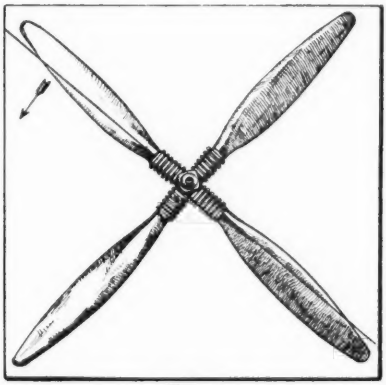


FIG. 1.

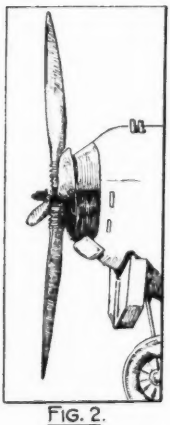


FIG. 2.

FIG. 4.

FIG. 5.

* *loc. cit.*

After some remarks on the value of variable pitch screws for multi-engined aircraft attention is drawn to a property of the design of screw in question in virtue of which if one engine stops the blades of its airscrew automatically adopt the position of minimum drag.

The screw, which had four blades, is shown in the sketches Figs. 1 and 2. Each blade is pivoted freely to the boss, the pivot axis being, apparently, normal to the aircraft shaft. The blade is staggered backwards in the plane of rotation, from 2° to 4° behind the pivot axis and is inclined slightly forward of that plane.

The angle is calculated from the conditions of equilibrium of the blade under the dynamic and aerodynamic forces, so as to give a suitable pitch for two chosen conditions of flight.

The action of such a screw is readily understood. When the engine is stopped the blades turn without difficulty as the centrifugal force on them is zero. The screw which is still running automatically reduces its pitch slightly, allowing the airscrew-engine combination to work at its best condition (Figs. 4 and 5).

The rest of the paper is concerned with a discussion of the possibility of using a variable pitch airscrew as an air brake for use in landing. These remarks only apply to a *controllable* pitch screw, since the required rotation of the blades is opposite to that given by the automatic type of screw as outlined above. To effect this the author considers the design of a screw involving hydraulic or electric servo control on the blade angle, the control lever being adapted to be coupled to the throttle lever if necessary.

No indication is given in the paper in question as to the method of operation of the servo control and nothing of the kind appears to be incorporated in the screw described and illustrated. Indeed, if it were applied, and that in such a way as to have sufficient range in pitch to reverse the thrust, the bending forces at the blade roots, instead of being materially alleviated as they are when the screw is used as an automatic variable pitch screw, would be increased, since the moments due to thrust and centrifugal force would be additive. The blades would also be in an unstable position kinematically and would have to be securely held by the controlling mechanism. With these complications the value of the screw would be seriously reduced.

On the other hand, in cases where the pitch angle assumed by the blades when freely pivoted is not quite the best for the conditions of flight prevailing at the time, it would be very convenient to have an auxiliary control by which small corrections to the " automatic " pitch could be made. This would involve small additional moments at the blade roots, but the change in pitch from the automatic value would never be large.

Possibly there might even be some advantage in some method, if sufficiently simple, by which the blades could merely be locked in the position in which they happened to be. The pitch could then be modified by manœuvring the machine, locking the blades, and then returning to the desired condition of flight.

FUELS FOR AIRCRAFT ENGINES

BY

F. R. BANKS, A.F.R.Ae.S.

(Paper read before the Coventry Branch.)

PART I.

SOME NOTES ON THE RELATION OF FUEL TO ENGINE DESIGN AND OPERATION

There has been a great advancement in recent years in the technique and production of suitable fuels for both aircraft and automobile engines and the author hopes that a few notes on the fuel problem with particular reference to aircraft work may be of help to those engaged on aero engine design and operation.

In the author's opinion it is somewhat surprising that, with the information and data at present available on the subject of fuels, greater use is not made of this when considering the design and operation of an aero engine.

During the late War, 1914-18, nobody really appreciated the importance of fuel with regard to engine performance. It was known that benzole could be added to a petrol and improved engine performance obtained thereby. Knocking or pinking was merely regarded as some mechanical feature or was loosely termed " ignition knock " which might have meant anything.

It would perhaps be more accurate to say that towards the end of the War at any rate it was beginning to be appreciated that fuel had something to do with the performance of an engine and when things had settled down to a peace-time basis numerous people in various countries proceeded to investigate the fuel problem of the internal combustion engine. Ricardo in this country has carried out a large amount of useful basic experimental work and is still continuing to do so.

The two investigators who in the author's opinion have done a tremendous amount of scientific experimentation on the fuel problem are Messrs. Midgley and Boyd in America.

They are also responsible for producing the first practical and cheap apparatus for testing the comparative anti-knock values of petrols.

Many other investigators at the same time have been, and still are trying to get down to the " basic " reasons which cause fuels to detonate, and there are many papers which have been written on this subject.

There is not space enough in a paper such as this to deal adequately with the findings and knowledge which have been compiled on the subject, but references are given at the end to one or two important publications which in the author's opinion should be studied.

Detonation

Detonation is a phenomenon attributable to the fuel alone. And some fuels are more prone to detonation than others when operating under similar conditions.

Briefly, the theory as to the cause of detonation is as follows: When the air/fuel charge in an engine is fired by the sparking plug the whole of the charge does not " flare up " and burn immediately, but it takes quite a measurable time for the flame which starts at or near the plug points to spread to the whole charge in the combustion chamber. The charge, therefore, may be said, almost, to burn in portions and those portions behind the flame front, which have already been

burned, expand rapidly and compress the remainder of the charge ahead of the flame front, to such a pressure and temperature that it ignites spontaneously before the flame reaches it. Therefore, instead of being burned in a more or less progressive manner the spontaneous ignition causes a rapid and uncontrolled pressure rise which occurs at such a speed as to cause a hammer-like blow on some portion of the piston and cylinder walls. The remark " on some portion of the piston and cylinder walls " is made advisedly as there is ample evidence to prove that the pressure caused by detonation is not an evenly distributed one over the whole of the piston and combustion chamber surfaces. It appears to be a " wave " effect produced by the rapid combustion of the detonating portion of the charge, this " wave " striking points in the combustion chamber and causing an audible knock or pink.

A comparison between a detonative and non-detonative fuel so far as the " mechanical " effects are concerned may be illustrated by the following simile: remove the cylinder head of any ordinary automoble engine and position one of the pistons to a point just over the top dead centre of the crank. One can then with comparative ease push the piston, by hand, down to the limit of its stroke. Now return the piston to its previous position again and give it a sharp blow with a hammer. This will not move the piston appreciably and may even break the head in. In other words, the blow is so sharp and the pressure applied for so short a period of time that it does not overcome the inertia of the working parts.

The pressure rise of the detonating portion of the charge is so rapid that it reaches its maximum in perhaps less than 1° of crank angle movement. Since detonation occurs at or about top dead centre of the crank it will be appreciated that this energy is dissipated before the piston can commence the power stroke and consequently this portion of the charge is wasted.

Yet another illustration may be given; compare the firing of a charge of cordite by means of a detonator filled with fulminate of mercury. The charge after firing burns relatively slowly and if used to propel a shell will give maximum propulsive effort, but supposing the cordite charge to be replaced by one of fulminate of mercury, the explosion would be so rapid and so uncontrolled that the gun would burst, without the shell even having left the barrel.

The author regards the foregoing theory as the " mechanical " cause of detonation and it was first propounded by Ricardo and has since been confirmed by other research workers.

Combustion chamber shape, the position of the sparking plug or plugs all have an influence on the performance of an engine with a given fuel and may aggravate the conditions which go to cause detonation. Obviously, if one takes the case of the old T-headed cylinder where the inlet valve is placed on one side of the engine and the exhaust on the other with the sparking plug somewhere over the inlet valve, it will be seen that the flame, when the charge is ignited, will have the maximum distance to travel, for a given volume, and, therefore, one has the best conditions from the point of view of causing detonation; as by the time the flame front of the burning charge has approached the pocket over the exhaust valve, not only has the unburned portion been subjected to considerable pressure and temperature, but it has also gained further heat from the exhaust valve itself and it detonates, to the detriment of the power output of the engine.

The turbulence of the charge is important, but this must not be overdone, otherwise a " rough " engine will result. The old T-head, however, can hardly be said to give turbulent conditions to the charge at all as it has considerable pocketing and by the time the charge has got past the inlet valve and round all the corners it has no energy left to turbulate.

It is well known that increasing compression pressures tend to cause detonation, but we all want to use these higher pressures to attain more power and also because a higher ratio of compression improves the thermal efficiency of the engine.

The fuel is the limiting factor to the raising of the compression pressure provided, of course, that the combustion chamber is the best compromise that can be obtained for the engine concerned.

Before leaving the subject of detonation it may be of interest to give briefly a theory for the " chemical " causes which make a fuel detonate. The theory put forward by the late Professor Callendar and which is the most feasible one so far propounded is as follows :—

" During the compression stroke with a petrol/air mixture the higher paraffins (the hydro-carbon group which are one of the constituents of a petrol) tend to persist as liquid drops and owing to their low temperature of ignition they ignite spontaneously and give rise to detonation. Also, intermediate products of oxidation, *i.e.*, peroxides, are formed and tend to accumulate in the drops. Substances like acetyl peroxide have been known for some time to detonate violently and they do, therefore, act as primers and the drops would ignite more readily."

Present Fuel Position

The Author would like to stress the point that he considers the time has now come to regard the fuel as a material in just the same manner as those materials are regarded which go to make up an engine. Once a specification has been settled it should be rigidly adhered to and the engine should not be called upon to operate on a fuel inferior to the one decided upon.

This procedure calls for the closest co-operation between the engine designer and the companies who supply fuels. With this co-operation the best can be got from the engine/fuel combination and a lot can be learned by both sides.

Most of the oil companies have laboratory equipment and can carry out fuel investigations in a practical and scientific manner and it is the author's experience that all the leading oil companies in this country have always been very ready to place their experience at the disposal of those who approach them.

In this country at the present time the chief customer of the aero-engine firms is the Air Ministry and most of the aero engines have been designed to meet the Ministry's requirements. To a certain extent fuel requirements have been considered, but it has been obvious for some time that with the high performances now demanded by the Air Ministry and which are being met by the manufacturers of both the water and air-cooled type of engine, a different outlook on the fuel question is necessary if all-round performance is to be obtained at ground level conditions as well as at altitude.

The present fuel, to Air Ministry specification, is one which consists of a mixture of " straight run " petrol and benzole or toluol. These aromatics (benzole, toluol) are added to bring the complete fuel up to the knock-rating required which is determined, at the moment, by a standard reference fuel consisting of equal volumes of pure crystallizable benzene and hexane.

There is a clause, namely, freezing point, in the Air Ministry Specification (D.T.D. 134) which virtually limits the amount of benzole which may be put into the base petrol. They specify that the freezing point must be below $-50°C$. Benzene, which is the principal constituent of benzole, has a very high freezing point, *i.e.*, about $+5°C$. It will be seen, therefore, that if the base petrol is of poor initial knock-rating the amount of benzole which may have to be added to bring it up to the Air Ministry requirements will be such that the freezing point will be raised very considerably above the figure laid down in the D.T.D.134 Specification. This would cause a considerable amount of trouble in the petrol and carburation systems when the engine is operating at high altitudes or in very cold climates. This is the reason for the proportion of benzole being reduced or its place being taken by toluol. Toluol is another constituent of benzole and has a very much lower freezing point than benzene, about $-90°$. If, however, much toluol is to be added it becomes rather an expensive procedure on account of the higher cost of production.

If an aero engine firm considers selling in the world's market, as it must do, it will be found in some countries that it is very difficult and sometimes impossible to obtain benzole and when obtained is often a very unclean product and may have a high sulphur content and contain other impurities which are injurious to the engine.

The chief consideration for an aircraft fuel is, high anti-knock value. The other points in the specification can easily be met now-a-days by the refiners. Any distillation range within reason can be given and all fuels can be fairly well cleaned up so far as sulphur and gum contents, etc., are concerned.

Ethyl and the Fuel

The author submits that the use of tetraethyl lead in a petrol would obviate the necessity of depending entirely upon benzole and maintains that more uniform fuels from the point of view of knock-rating could be universally obtained.

There are some misconceptions concerning tetraethyl lead and the following remarks may help to clear these up. The addition of " lead " to a petrol does not alter the characteristics of that petrol in any way whatever except from the point of view of knock-rating, that is to say, its specific gravity is not measurably altered and the distillation range remains the same. In other words, the petrol is really a " carrier " for the " lead " and it is the most convenient way of introducing the latter into the combustion chamber and mixing it intimately with the fuel/air charge.

The proportions in which the " lead " is added to the petrol are very small indeed. They naturally vary according to the anti-knock value required and to the class of base spirit which is employed, but if one considers that 3.5 c.c.'s of " lead " per Imperial gallon (4,545 c.c.'s) is a reasonably large amount to add to a petrol to give it a high anti-knock value, it will be realised how effective this substance is. On a volume basis it is about 600 times more effective than benzole.

The fact that it can be used in such small quantities is of great importance when considering mixing fuels in various parts of the world, since such a small quantity of " lead " can deal with a very large quantity of petrol. The addition of " lead " does not upset the freezing point of the fuel which for ordinary petrol is about $-120°C$. It will be appreciated, therefore, that if " lead " is used to improve the anti-knock value of a fuel this will allow the use of petrols which would otherwise be barred on account of their poor initial knock-rating due to the fact that an excessive amount of benzole would, in the normal course of events, have to be added with a consequent raising of the freezing point above the limit for satisfactory engine operation in cold climates or at high altitudes.

A further point as to the usefulness of tetraethyl lead is that under high temperature conditions such as those pertaining in an air-cooled aircraft engine a petrol with " lead " added to it still retains its anti-knock value to a high degree, whereas the same petrol with benzole added to it to give it the same initial anti-knock value as the " leaded " fuel will, generally, decrease in anti-knock value as the temperature increases. Again, if two similar fuels, one containing " lead " and one containing benzole, both having the same knock rating, are run in an engine and the temperature of the cylinder head taken it will be found that the engine will run at a lower cylinder head temperature on the " leaded fuel." See Figs. 1 and 2.*

Increasing amounts of benzole in a fuel even although the fuel may be above detonation point generally tend to raise the mean operating temperatures.

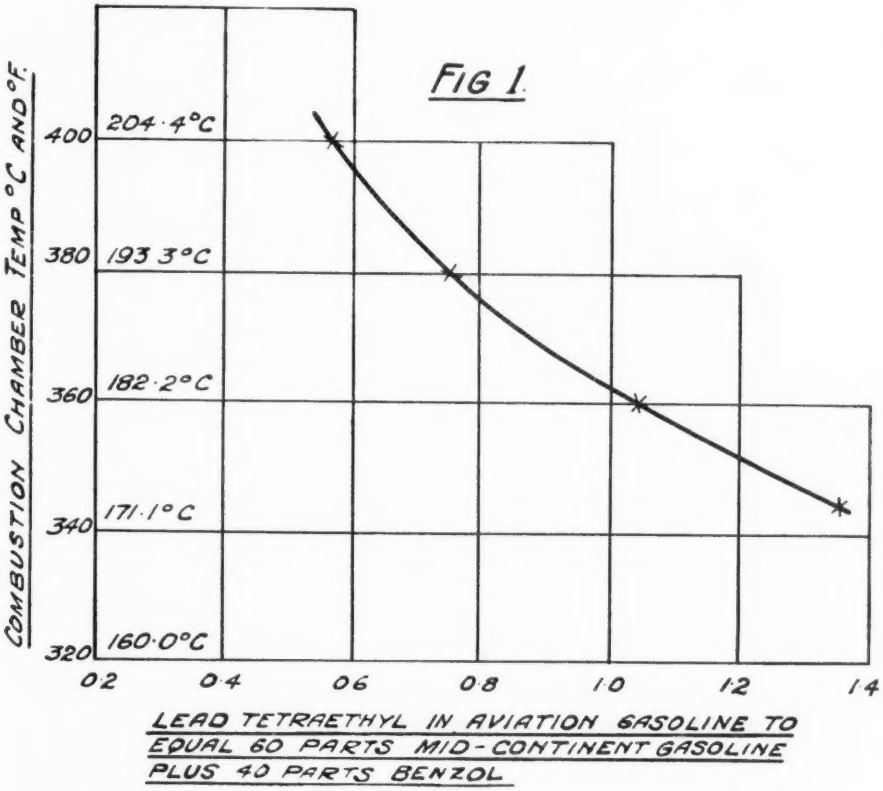
Tetraethyl lead for addition to fuels for internal combustion engines is made up and sold in the form of " Ethyl " fluid. It is not practicable to use tetraethyl lead alone, as the lead oxide, formed after combustion, might cause trouble as

* Fig. 2 represents the results of some tests carried out by Pratt and Whitney, Hartford, Conn., U.S.A.

a deposit. The fluid, therefore, is designed to eliminate any possibility of this trouble and contains a percentage of ethylene dibromide which converts the lead oxide to a bromide, a perfectly harmless deposit, the bulk of which passes out through the exhaust port.

The deposits, in an engine in which ethyl has been used, show a different colour to those which are normally found when ordinary fuel has been employed. This is due to the bromide, just referred to. These deposits are of a slightly harder nature than the carbon formed under ordinary conditions.

It will be found, too, that for a given running time the deposits from a " leaded " fuel are usually less than, say, those from a petrol/benzole mixture.



Design and Operation

Aero engine design is all a compromise as in fact is any design which concerns practical engineering.

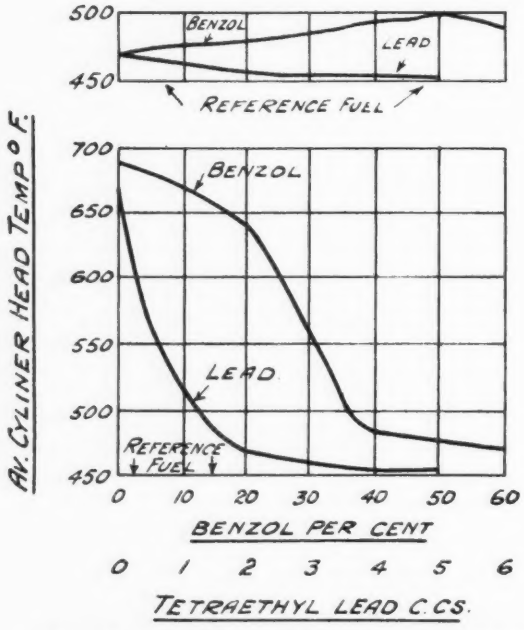
The bugbear of an aero engine designer is " frontal area." He must reduce this to a minimum compatible with the horsepower he wishes to obtain from his engine. In doing this he has, very often, to subordinate the combustion chamber shape to such items as the overall dimensions. That is to say, he may have to use a rather ordinary combustion chamber shape and a low stroke-bore ratio,

this makes for a flat (in section) type of combustion chamber and not necessarily the best from the point of view of eliminating detonation.

At the same time, as the fuel consumption is of paramount importance the highest compression ratio possible should be used to obtain fuel economy consistent with the smooth and satisfactory running of the engine.

In Fig. 3 the author gives a curve of Air Standard Efficiencies at various compression ratios and it will be seen that this flattens out somewhat from about

FIG. 2. REDUCTION IN CYLINDER HEAD TEMP. FROM USE OF ANTIDETONANTS.



THE TESTS RECORDED IN THE UPPER CURVES WERE MADE ON CALIFORNIAN DOMESTIC AVIATION GASOLINE H.U.C.R. 5·8 - 1. THE LOWER CURES ARE BASED ON A MID-CONTINENT D.A.G.

7/1 to 10/1 and while it may appear very agreeable to be able to run at compression ratios above 7/1, considering, of course, full throttle ground-level conditions, it must be borne in mind that with whatever fuel is used it may be of doubtful advantage to go above this figure as the improvement in fuel economy will be relatively small and the increase in maximum cylinder pressures relatively large.

The author considers that a great deal more can be done in the future by using compression ratios up to say, 7/1, and with the employment, for increased power, of a supercharger. Very much improved results so far as fuel economy is concerned can also be obtained by the improvement of induction systems and the use of fuels having boiling ranges to suit the systems employed.

The advantages of using a fuel of high anti-knock value are many, but there is one particular feature which is not generally recognised; if a fuel of good anti-knock value is used it enables the engine to operate up to its capacity without detonation and a certain degree of fuel economy may be obtained by "leaning" the mixture. Quite a number of engines operate, according to their designers and operators, without detonation and on "any old fuel," but it will be generally found that the fuel consumption is unnecessarily high because a "rich" mixture has to be employed to keep the engine cool and free from detonation.

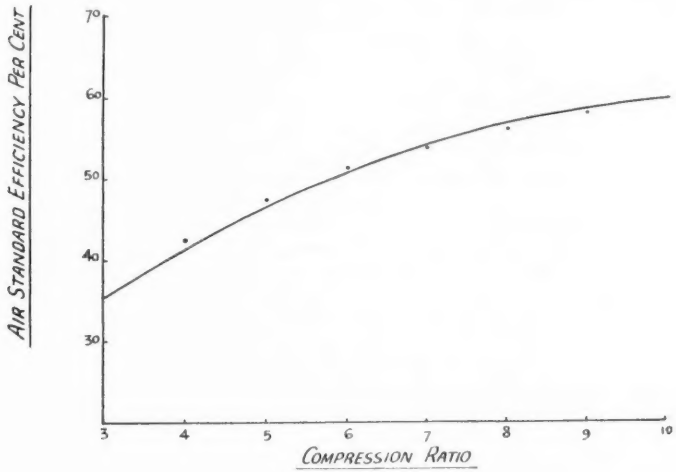


FIG. 3.

Air standard efficiency $[E = 1 - (1/r)^{1.408 - 1}]$

In some cases the lubricating oil consumption in engines has been improved by the use of a more suitable fuel. The author has had experience of piston trouble in engines which was not cured by alterations in the grade or class of lubricating oil or by increasing the amount of oil. It was eventually found that the engine was operating under conditions of detonation and that the pistons must have been working at unduly high temperatures. A change of fuel improved the conditions to such an extent that no further trouble was experienced.

There have been cases on air-cooled engines where the cylinders due to the use of an unsuitable fuel have shown operating temperatures 150°C. above normal. Unfortunately, it is very difficult to detect the condition of detonation in an aircraft engine and the only really useful method is to take cylinder temperatures when running on different fuels. The members of all aero engine firms appreciate the difficulties of obtaining accurate or even comparatively useful temperature measurements on an aircraft engine cylinder and when somebody is able to

produce an apparatus which will do this satisfactorily it will be of very great help to the manufacturers and the fuel suppliers.

The air-cooled engine manufacturers have by far the most difficult time of it as in addition to the " hot spot " in the form of an exhaust valve they may have, according to the way the engine is installed in the machine, a number of " hot spots " due to bad air flow, or, no flow at all about the cylinder heads.

The author considers that the first duty of an aircraft engine designer is to eliminate as many of these " hot spots " as possible in the initial design. In this connection the development of the internally cooled (sodium filled) exhaust valve should be very helpful. It has been said by some people who have fitted these valves that they cannot find any difference in the running of their engines, but it should be appreciated that some engines may be running well below their rated horse-power and therefore under very " cool " conditions. It is possible that the effect of " leaning " the mixture strength in an attempt to obtain better fuel consumption has not been considered. Again, when using these valves, it might have been possible to re-rate the engine to give higher output with safety and also to increase the compression ratio with benefit. The design of the internally cooled valve is important and it is no use filling it with sodium which is remote from the valve head. The filling should be brought as near as possible to the hottest part of the valve and in this connection hollow forged valve heads are being experimented with and will be very satisfactory provided that their mechanical strength is unimpaired.

In one particular case within the author's knowledge the fuel consumption of an aero engine was improved by about 0.07 of a pint per B.H.P. hr. by the fitting of sodium-filled valves alone. Naturally, when an internally-cooled exhaust valve is fitted, some modifications must be made to the valve guide. This is generally only necessary in the case of an air-cooled engine. The heat which travels up the guide must be dissipated adequately, and it is admittedly not an easy problem to solve on the air-cooled job, particularly where there is no oil " splash " or circulation around the end of the valve stem. With some of the austenitic steels used in exhaust valves certain " picking up " in the valve guides occurs, and this is accentuated with an internally-cooled valve as the stem temperature is considerably raised. The rate of wear between the guide and the valve stem may tend to increase, and the heat will then travel up to the top of the stem and cause trouble at this end. In all water-cooled engines, to the writer's knowledge, in which this class of valve has been fitted practically no modifications at all have been necessary, but it must be remembered that the valve guide in a water-cooled job is generally surrounded for most of its length by water, and the valve stem has adequate oil " splash " at the operating end. The foregoing points are put forward to assist those who may be considering the adoption of this class of valve. Reference is made, at the end of this, to a Paper on the salt-cooled valve.

The author does not wish to give the impression that he is writing a treatise on engine design, as this is far from the case. Fuel and engine design, however, are so wrapped up in one another that it is not possible, in the light of modern experience, to consider one without the other.

An aero engine designer will design a really good engine, and it may be thrown back to him as a failure by the engine operators who have bought it, and items such as valves, cylinders and pistons will be reported as always giving trouble. An investigation may show that this engine has been consistently operated on fuel which is entirely unsuitable for it. It is, therefore, very difficult to say whether such parts as the exhaust valve or piston are badly designed if they are constantly failing, unless it is certain that the engine is being run as it should be, *i.e.*, with suitable fuel and oil.

Part II.

Fuels. Methods of Testing and Assessing their Anti-knock Values

General Considerations

It is generally known that crude oils differ in their physical and chemical characteristics according to their source of supply.

There are three groups of the hydrocarbon series which generally characterise the spirits obtained from the various crude oils. These are: The paraffin, the naphthene and the aromatic series.

Taking " anti-knock value " as the predominating factor, the order of merit for the effectiveness of the three hydro-carbon groups under *all* conditions would be:—(1) Naphthene, (2) Aromatic, (3) Paraffin.

Unfortunately the classes of fuels given in (1) and (2), containing relatively high proportions of the hydro-carbons mentioned, are not always available to be distributed commercially and in large quantities. A certain degree of blending must be resorted to by the companies marketing any class of spirit to effect the best compromise between distribution and uniform quality. That is to say, a stock of very good petrol, from an anti-knock point of view, is laid aside to treat large available supplies of a petrol which may be poor in this characteristic.

The boiling or distillation ranges of petrols, good and poor in anti-knock value, can be suited to the class of work they have to perform and in this connection it is interesting to note that the addition of " lead " to any petrol does not measurably alter its distillation range.

For a " straight run " petrol of " aviation " grade the boiling range lies, approximately, between 40°C. and 165°C. The former is known as the initial boiling point and the latter the final boiling point. This, however, is not sufficient to gauge it from the point of view of satisfactory carburation. The percentage of petrol distilled over at the intermediate temperatures, every 10°C., must be found and this can vary according to the basic features of the petrol, but for all practical purposes, as mentioned before, it can be refined to meet requirements.

For easy starting and good acceleration the amount distilled over from the initial boiling point to about 100°C. is of great importance and the author gives herewith some average figures:—

I.B.P.	...	40°C.
At 50°C.	...	= 5% not less.
,, 70°C.	...	= 17% approx.
,, 100°C.	...	= 50% not less.

With about 90 per cent. of the total distilling over at 150°C. The foregoing is to be regarded as an illustration only and it gives some idea of the general shape of the distillation curve.

Some operators consider that the " 10 per cent. point," *i.e.*, the temperature at which 10 per cent. of the distillate is recovered, is important and should be about 65°C.

If benzole is added to a petrol this will alter the shape of the distillation curve. Benzole is a mixture of benzene, toluene, with a trace of xylene. The benzene predominates. All three constituents are constant boiling liquids, the B.P. of benzene being 80°C., toluene 110°C. and pure xylene about 140°C.

The average motor benzole has a boiling range between 80-110°C. and its addition to a petrol will, obviously, increase the percentage distilled over between these points.

The author has digressed somewhat but considers such digression justified in order to give some idea of the significance of the term " distillation range."

Testing for Anti-knock Value

There are, at present, two separate methods used for testing the comparative anti-knock values of fuels and these may be termed (*a*) the variable compression method and (*b*) the fixed compression method.

(*a*) *Variable Compression Method.*

This method makes use of a single cylinder engine, coupled to an electrical dynamometer to absorb the power. The cylinder head can, by suitable mechanism, be raised or lowered while the engine is running, thus increasing or decreasing the volume of the combustion chamber space above the piston.

The engine is run on a fuel, the knock-rating of which is to be ascertained and after the engine has warmed up and test conditions have been stabilised, the operator starts to increase the compression ratio (by lowering the cylinder head) until a knock or " pink " just becomes apparent. Fuels may thus be tested against one another, or against a reference fuel of a predetermined knock value, where blending to equal knock-ratings is required.

The compression ratio can be accurately set by means of a micrometer adjustment on the cylinder. The knock values of the fuels are given in terms of " highest useful compression ratio " (H.U.C.R.). That is to say, one fuel may have an H.U.C.R. value of 5.2/1 and another 5/1, the latter fuel has the lower anti-knock value.

The credit for the first variable compression engine produced should go to Mr. Harold Moore who, it is believed, built one at some period during the late War. Mr. Ricardo, however, was the first man to bring this type of engine into practical use for fuel testing work.

There are, in the author's opinion, some objections to the use of the variable compression engine for the ordinary and comparative testing of fuels. It is a comparatively slow method when a number of fuels have to be tested, due to the inherent difficulty of ascertaining, accurately, when audible detonation in the form of a knock, takes place.

An operator, skilled in the use of the engine, should be employed the whole time on the unit if reasonably accurate results are to be obtained.

The operator should have a month, or more, intensive work on the engine before commencing routine fuel testing.

One of the main difficulties in testing fuels is to ensure that there is the least possible number of variables during the test. The variable compression engine with its consequent alteration of combustion chamber size and shape, during running, increases rather than otherwise, the number of these variables.

(*b*) *Fixed Compression Method.*

This method was first evolved by Midgley in America, whose researches with Boyd eventually led to the discovery of the remarkable effect of tetraethyl lead as an anti-knock compound for motor fuels. Briefly, it consisted, in its early form, of an ordinary single cylinder " Delco " lighting set with a load resistance to absorb the power given out by the generator and maintain a steady load on the engine which was set to operate at a constant speed, 600 r.p.m. The compression ratio was raised from normal and fixed at about 6.5/1.

Screwed into the cylinder head was a tube or body about 7in. long fitted with a steel diaphragm in one end, flush with the combustion chamber surface, and at the other end were two electrical contact points mounted on fairly long blades.

Between the lower contact blade at one end and the diaphragm at the other was a steel rod about $\frac{3}{16}$in. to $\frac{1}{4}$in. in diameter.

This was known as the bouncing pin. It rested by its own weight on the diaphragm and was fitted with a fibre tip at the contact point end. It was a slack fit in the body.

The contact points were in circuit with a battery and an electrolytic cell. This cell was of glass and contained dilute sulphuric acid, one " arm " of the cell being graduated in 0.10 c.c.

A stop watch was included in the equipment.

The engine was fitted with a single jet double weir type carburettor so that any differences in the specific gravity of the fuels could not upset the fuel level at the jet. The weir chambers were interconnected by means of a three-way cock so that they could be quickly switched over to the jet in turn. There were separate feeds to the chambers from fuel bottles above and the overflows from the weirs were taken away separately, to bottles below. One bottle fed the standard reference fuel to one chamber and one supplied the other chamber with the fuel to be tested against the reference fuel.

The cooling of the engine was by water in an enclosed circuit employing a reflux condenser, the outlet temperature at the cylinder head being maintained at 100°C.

The whole idea of this equipment was to keep the test conditions as constant as possible. Constant speed, temperature, ignition, throttle and carburettor settings and fixed, or constant, compression ratio.

The engine was operated at comparatively low speed with a high compression ratio in order that it would knock on all fuels within a wide range, even on the reference fuel. The *degree* of knock between the reference fuel and the sample fuel was then measured by the bouncing pin arrangement in the following manner: As the engine operated under detonating conditions the whole time the pressures thus generated in the cylinder deflected the diaphragm in the bouncing pin body thus making the pin jump up and complete the electrical circuit by bringing the two contact points together. In doing this, gas was generated in the electrolytic cell the volume of which could be measured over a period of time, usually one minute, and read off against the graduations on the cell.

The procedure for matching a fuel to a predetermined reference fuel being as follows:—The engine was run on the reference fuel until stabilised conditions were established. Alternate readings were then taken, of one minute duration, of the reference fuel and the sample under test and the average of about half a dozen readings of the gas volume in the cell, for each fuel, was obtained.

To bring the sample under test up to the reference fuel standard, tetraethyl lead was added to the sample until it gave the same readings as the reference fuel and the value was given in terms of " lead " added per gallon of the sample, *i.e.*, " +2.5 c.c.s " would mean that the sample was below reference standard by that amount of " lead " per gallon and 2.5 c.c.s would have to be added to bring it up to standard.

The reference fuel was usually a suitable mixture of a " straight run " mid-Continent spirit and benzole or, alternatively, " lead," to give an anti-knock value which had previously been settled upon as being satisfactory.

The great advantage of the bouncing pin method using a fixed compression ratio over that employing variable compression is that the former may be operated with relatively unskilled labour after a short period of practice and it does not depend upon the human ear to discriminate between the knock values of the fuels. All the operator has to do in the former case is to be able to read the graduations on the gas cell.

A far greater number of fuels can be tested in a given time by the bouncing pin method, which is important from the point of view of routine tests in a large laboratory.

The old " Delco " set has now been entirely redesigned and improved upon and is now known as the Series " 30 " Engine. It is manufactured by the Ethyl Gasoline Corporation in America. A much stiffer crankshaft is now fitted and the engine drives a synchronous motor which ensures that there is no fluctuation in the speed of the engine during tests. The carburettor has adjustable float

bowls so that the mixture strength characteristic for the maximum knock condition of each separate fuel tested can be adjusted for.

The engine is also designed to employ the higher boiling liquid coolants, such as ethylene glycol, so that fuel tests can be carried out at jacket temperatures varying from 100°C. to about 150°C.

Method of Assessing Anti-knock Value

One great difficulty in assessing the anti-knock value of a fuel is the question of the make up of the reference fuel against which all the sample fuels are to be tested, and also the terms in which the anti-knock value of a fuel can be expressed to be clear to all those engaged on work where the question of fuel characteristics comes in. It, the reference fuel, should be a very stable substance of known characteristics so that it can be used by different laboratories and comparable results obtained.

Care must be taken to see that it is stored in a proper manner. If it is at all volatile and is stored carelessly it may lose its volatility. Its anti-knock value may be lowered in consequence.

The latest developments in the production of a suitable reference fuel have taken place in America. The following two compounds have been found to give very uniform results as a reference fuel, when used separately or mixed in various proportions, namely, octane and heptane. They are pure hydrocarbons, which is very important when considering the adoption of a primary knock " scale."

These two hydrocarbons are, at present, being made in the laboratories of the Ethyl Gasoline Corporation. Unfortunately they are very expensive to produce, costing about £6 per imperial gallon, at normal rates of exchange, so that a sub-standard reference fuel is generally used for routine testing and this is checked at intervals against the octane/heptane fuel by running the engine on a known mixture of the latter.

Octane has a very high anti-knock value and it is well above all classes of petrols. Heptane has pro-knock characteristics to a marked degree.

The octane/heptane " scale " is evolved as follows:—It is the percentage of iso-octane (2.2.4 trimethylpentane) in normal heptane. At one end of the scale we have 100 per cent. heptane which equals octane No. 0 and at the other end 100 per cent. octane which equals octane No. 100. That is to say, if one refers to a petrol as having an " octane No. of 70," it means that the anti-knock value of that petrol is equivalent to 70 per cent. octane in 30 per cent. heptane

At the moment, the standard tests for assessing the anti-knock values of petrols are run with a jacket temperature (on the test unit) of 100°C., but, for aviation fuels, it has been found that tests carried out employing a jacket temperature of 150°C. give better indication of the suitability of a fuel for operating under conditions of high duty as in an aero engine. For instance, a fuel may have an octane No. of 75 when tested at 100°C. and only one of 71 at 150°C. However, in this country the earlier conditions of test still prevail although the author considers that some investigations should be started immediately on the question of assessing the knock ratings of aviation fuels under high temperature conditions.

It may be of interest to give the anti-knock values of one or two typical petrols so that some idea may be obtained regarding the significance of " octane No." when applied to a fuel:—

TABLE I.

Petrol.	Octane No. (at 100°C.).
Air Ministry Specification, D.T.D. 134	... 76 approx.
Ethyl Petrol	... 78.0 not less than.
Good " No. 1 " on British Market ...	... 67-72 not less than.
" Commercial " Grades	... 60-65 not less than.

General Remarks

With normal fuels such as petrol and benzole it is not possible to obtain marked increase in the power output of an engine by using different grades of the former or mixtures of both, as their internal energy for a given volume, in the case of petrols, is about the same and their latent heat value does not vary much above or below 135 B.T.U.s per lb. Benzole has a lower internal energy for a given volume than the petrols, but this is balanced out due to the fact that its latent heat is higher, about 164 B.T.U.s per lb. The foregoing assumes, naturally, that no detonation is present when considering the relative power output with different fuels.

The only way, therefore, that the power of an engine can be increased is by taking the fullest advantage of fuels having high anti-knock values, say, 80-87 octane and designing the engine accordingly, employing high compression ratios and supercharging.

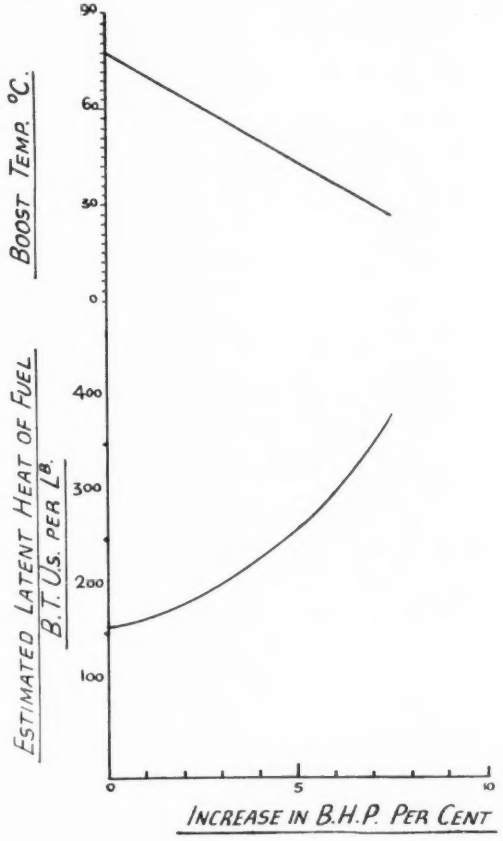


FIG. 4.

Curves showing increase in power and drop in boost temp. on a highly supercharged engine using fuels of increasing latent heat.

For very special work many things can be done in the way of making up fuels to give substantial increase in power to engine. The author has in mind the last Schneider Contest and the recent world's record attempt where he was given a free hand by the engine manufacturers to provide suitable fuels for both events. The constituents of the fuels were: Ethyl, petrol, benzole and a certain class of alcohol.

In the case of the Schneider Contest the specific fuel consumption had to be limited to a figure not exceeding 0.60 pt. (0.62lb.) per B.H.P. hr., but notwithstanding this, an increase of power, on the change of fuel alone, of nearly 100 B.H.P. was obtained against that possible with the old fuel evolved in 1929.

For the speed record the limit placed on the specific consumption was much higher (about 0.90 pt. per B.H.P. hr.) on account of the shorter time in the air. The fuel in this case was responsible for an increase of between 200 to 300 B.H.P.

A fuel, however, is only as good as the engine makes it and it is a tribute to the Rolls-Royce " R " engine that it absorbed the fuel and stood up to such phenomenal powers without murmur.

These fuels make use of the relatively high latent heat of alcohol, which is more than three times that of an ordinary petrol, to increase the density of the charge, thus ensuring a greater charge weight is taken into the cylinder per induction stroke.

Alcohols are, in the ordinary course of events, too expensive from the point of view of specific fuel consumption as their calorific values are very low, about half the heat value of petrol. They are, therefore, hardly practicable for anything except very special work such as the foregoing. Some curves are given in Fig. 4 showing the effect which the increase of latent heat of the fuel can have on engine performance.

The " boost " temperature curve in Fig. 4 must only be regarded as approximately correct as it is always very difficult to get accurate readings of induction pipe temperatures. This difficulty is due to the " wet bulb " effect on the thermometer. These temperatures, however, may be considered as having some comparative value as the mean volatility of the fuels tested did not vary very much.

In connection with highly supercharged engines employing " boost " pressures of two atmospheres absolute or more, it must be borne in mind that the high induction pipe pressures affect the volatility of the fuel considerably and the whole boiling range of the fuel is raised, therefore a fuel having a range between 50 and 150°C. at atmospheric pressure will, under a pressure of two atmospheres absolute, have a boiling range very much higher than the average commercial petrol on the market for automobiles. Reasonable care, therefore, should be taken when considering the use of various fuels under high " boost " conditions.

Conclusion

In conclusion, it is hoped that this paper may be of some small assistance to those engaged on aero engine design and operation, and the author will be well satisfied if it only gives them to think about the fuel when selling and operating engines over the world.

Some Papers Recommended

1. " The High Performance Gasoline Aircraft Engine," with its problems of fuel, oil and materials of cylinder construction. By S. D. Heron. A.S.M.E. Paper delivered 20th May, 1931.
2. " Symposium on Aircraft Fuels." Being six Papers presented at the National Aeronautic Meeting of the S.A.E. in Chicago, August, 1930.
3. " Detonation Symposium." Papers presented at the 1931 Annual Meeting of the S.A.E. Reprinted from S.A.E. Journal for June, 1931.
4. " Technical Description of the Salt Cooled Valve," by Robert Jardine. Reprinted from " Aviation Engineering " for July, 1931.
5. " High Temperature Knock Testing," by Graham Edgar. " Aircraft Engineering," July, 1931.

REVIEWS

Heavy Oil Engines of Akroyd Type

William Robinson. (Blackie and Son. 7s. 6d.)

This book gives a good account of the development of the heavy oil engine by Herbert Akroyd Stuart from about the year 1890, and concludes with a few typical examples of modern engines. In discussing Akroyd Stuart's work, Mr. Robinson becomes rather an advocate than a judge, an attitude which can easily be excused in a man supporting the reputation of a friend. But his book is, unfortunately, marred by defects of style which suggest that it was written too hurriedly.

There is no doubt that Akroyd Stuart was the first to produce an oil engine on the principle of spraying liquid fuel into a mass of hot compressed air, this mass being hot enough to cause the oil to ignite immediately. But in all his early engines the heat in the air was obtained partially by the heat of compression and partially by compressing the air into a red hot bulb. He seems, at any rate in the early days, to have had no idea that the necessary heat could be obtained by compression alone. This conception seems to have been originated by Dr. Diesel, and as time went on the bulb became smaller as the compression was raised and eventually disappeared altogether, so that the two types became similar in this respect.

A lesser difference is that Akroyd Stuart injected his fuel by a pump while Diesel employed compressed air. In this case pump injection promises to supersede compressed air, especially in high-speed engines.

No one who has studied Akroyd Stuart's work can doubt his right to belong to the select body of men who have made important fundamental inventions and this work is a useful reminder of what we owe to him.

Year Book of the D.V.L., 1931

(R. Oldenbourg, Munich. 62 marks.)

The Year Book of the D.V.L. (German Experimental Institute for Aviation) contains 260 investigations summarised in abstracts, but about 58 of them are completely republished. About half of the last mentioned reports are published here for the first time, which means a departure from early practice. As an aid for readers, interested only in definite questions of the D.V.L. work, the different parts of the Year Book are to be obtained as separate booklets. So one may have single Reports of the Research Departments for Aerodynamics, Statics, Engines, Materials, Aerial Photography and Navigation, Electrotechnics and Wireless, Flying.

Within the scope of the aerodynamic investigations may be mentioned model tests on artificial ventilation of engine test benches and trial runs with propeller driven speed car. Under Statics we have reports on structural requirements and the results of tests with aircraft parts; two investigations relate to calculations of space framework. The papers of the Engine Department include some on the mechanical properties of spark-ignition aero engines under different service conditions, trials with a supercharger, possibilities of the use of waste gas in jet propulsion—an important paper in view of the present interest in this form of propeller—torsional oscillations of engines in tandem and studies of knocking.

Two very thorough investigations of the Material Department relate on the one hand to welding properties of steel parts for aircraft, and on the other to static and dynamic strength of different light metal alloys. Other papers deal with corrosion tests of sheet material and cables, trials with finishing materials and fuel research. The Department for Aerial Photography and Navigation publishes among others a paper on the distortion of lenses, and two others on increasing the sensitivity of photographic emulsions.

From the papers of the Electrotechnics and Wireless Departments two new investigations may be cited. One relates to the influence of the position of the sun upon wireless waves; and the other to auto direction finding by radio. The Reports of the Flight Department deal with Handley Page slotted ailerons; the influence of the slipstream upon the rudder; and determination of the effect of wing contours and aileron size upon the lateral manœuvrability of monoplanes.

Considering that the removal of the D.V.L. to a new site is scarcely completed, the institute is to be congratulated on a remarkable year's work.

Angles on Practical Flying

P. W. F. Mills. (Crosby Lockwood and Son. 4/6 net.)

The Author has apparently compiled this book largely from the gossip he has heard at the various aerodromes he has visited. The views of aerodrome gossipers on technical matters are frequently marked by ignorance rather than by any other quality, and the author appears to be unable to distinguish between this type and the select few who possessed real knowledge. The result is a book which contains a certain amount of useful matter diluted by a large number of absurdities.

For instance, we are told on page 18 that stability in what the author calls the rolling plane is given by arranging the centre of gravity to lie below the centre of lift, a pendulum effect being thus given to the weight of the aeroplane. Unfortunately for this ingenious theory, low-wing monoplanes can easily be made stable in this plane.

We are also told, on page 19, that the greater weight of the aeroplane prevents it from revolving round the propeller!

And again, on page 31, that the objection to a heavy engine is that it requires greater structural support which increases the weight of the aeroplane as a whole. I can only assume that the author thinks that aeroplanes do not lift their own engines, though if this is so it is not easy to see why he believes a heavier mounting to be necessary for a heavier engine.

On page 52 he remarks: The effect of a " speed skid " may be manifested on any plane. It is a translatory motion arising out of the natural tendency of a moving object to maintain its original direction when deflected, and the motion continues until it is balanced by an applied force of equal and opposite tendency. This will be recognised as being what in mechanics is called " centrifugal force."

Whatever this statement means, it bears no resemblance to any force known to man, the object apparently is and isn't deflected at the same time.

This is a book to be avoided. I assume that it is written to teach the young pilot something about his aeroplane and the way it behaves. In this it fails completely, as it is much more likely to mislead than to instruct.

Aeroplane Construction and Repair

By J. E. Younger, Ph.D. (McGrand Hill Book Co.)

This book, which is intended for the use of Aeroplane Mechanics, deals comprehensively with the inspection, repair, and assembly of aircraft as carried out in America.

American methods of making repairs are clearly dealt with, and the book is very well illustrated.

Methods of repairing wooden machines are well explained, and there is a chapter on glueing; and it is interesting to learn that wood construction is still used for most of the best American aircraft.

A chapter is given on doping and finishing, where the strange mistake is made of stating that cellulose nitrate is produced by "dissolving" cotton in nitric acid, but which is otherwise full of valuable practical hints.

The various methods of welding, either by oxy-acetylene or oxy-hydrogen blow-pipes and by the various electrical methods are well dealt with. While a reference is made to the fact that acetylene gas produced in generators often contains undesirable impurities it is curious to find no reference made to purifiers.

Thin sheet metal is discussed, and the methods used for the repair of parts made from this material are described, and there are final chapters on cleaning, oiling and adjusting aircraft and assembling rigging and inspecting.

The book contains an immense amount of practical information, most of which has not, I believe, been previously published—at any rate, in so convenient a form—but the reader should remember that in certain instances American practice would not be accepted in this country. The very bad design for an elevator control stick connecting link given on page 27 is a case in point.

The book can be thoroughly recommended to those interested in the repair and maintenance of aircraft, with the reservations that have been given, as those who desire to be abreast of their subject cannot afford to ignore the practice of other countries. Its chief value is its detailed description of American practice in the matters with which it deals.

CORRESPONDENCE

To the Editor of the Journal of the R.Ae.S.

Ingleston, Osborne Road,
East Cowes, I.W.,
November 20th, 1931.

Re The Method of Least Work

Dear Sir,—With reference to the stressing of self-strained redundant structures, it has occurred to me that the difficulty mentioned in my paper on the Method of Least Work (July Journal, p. 662, line 20) can easily be dealt with as follows:—

Consider the case where there are two redundant members with known initial loads P_{01} and P_{02} respectively. The unknown amounts by which these members are short when all the members are unstrained are λ_1 and λ_2 respectively.

When the members are strained into position in the structure, the relative deflections of the ends of the members and their points of attachment, namely, λ_1 and λ_2, are given by $\partial U_0/\partial P_{01}$ and $\partial U_0/\partial P_{02}$, where U_0 is the initial strain energy of the complete structure (including the redundant members).

Now the final load in each member can be expressed in the form $\alpha+\beta P_1+\gamma P_2$, where α, β and γ are constants for each member. The initial load in each member is then of the form $\beta P_{01}+\gamma P_{02}$, so that

$$\lambda_1=\partial U_0/\partial P_{01}=\Sigma\,(l\beta/EA)\,(\beta P_{01}+\gamma P_{02}) \quad . \quad . \quad . \quad (1)$$

$$\text{and } \lambda_2=\partial U_0/\partial P_{02}=\Sigma\,(l\gamma/EA)\,(\beta P_{01}+\gamma P_{02}) \quad . \quad . \quad . \quad (2)$$

When the external loading is applied, the respective values of the loads in the redundant members become P_1 and P_2, which may be found from the equations

$$\partial U/\partial P_1 = \Sigma\,(l\beta/EA)\,(a+\beta P_1+\gamma P_2)=\lambda_1 \quad . \quad . \quad . \quad (3)$$
$$\partial U/\partial P_2 = \Sigma\,(l\gamma/EA)\,(a+\beta P_1+\gamma P_2)=\lambda_2 \quad . \quad . \quad . \quad (4)$$

Although the same general expression $\partial U/\partial P = x$ has been used twice over for each member, the particular form is different in each case. In the initial case, $a=0$ and P_{01} and P_{02} are known; hence the values of λ are determined. In the final case, a is known and P_1 and P_2, which are unknown, can be found.

Instead of working out the values of λ from (1) and (2) and using these in (3) and (4), we can equate (1) to (3) and (2) to (4), giving

$$\Sigma\,(l\beta/EA)\,[a+\beta\,(P_1-P_{01})+\gamma\,(P_2-P_{02})]=0$$
$$\text{and } \Sigma\,(l\gamma/EA)\,[a+\beta\,(P_1-P_{01})+\gamma\,(P_2-P_{02})]=0$$

from which values of (P_1-P_{01}) and (P_2-P_{02}), and hence P_1 and P_2, can be found; and similarly for any number of redundant members. It will be seen that this simply amounts to another way of stating the method dealt with in remark (6), p. 655; *i.e.*, finding the loads due to the external loading by the method of Least Work, and adding the initial loads. Thus, unless the self-straining is given in the form of values of λ, there is no point in introducing λ into the calculation, though there is no difficulty in so doing if desired.

Yours faithfully,

FRANK G. EVANS.

To the Editor of the Journal of the R.Ae.S.

11th January, 1932.

Dear Sir,—I was interested to note in this month's issue of your journal the review of the second edition of my book on "Stainless Iron and Steel."

May I refer to the last paragraph of the review and suggest to the writer of it that if he will turn to pages 529 and 530 of the book he will find given thereon the information which he deems omitted? He will also find reference to this page number in the index under the word "Seizing." The data regarding seizing was placed in the position it occupies (namely, in that part of the book dealing with the engineering applications of stainless steels) because the phenomenon of seizing is not confined to high chromium steels as your review writer suggests, but is a characteristic of all types of stainless steel.

Yours faithfully,

J. H. G. MONYPENNY.